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EVS 601

Environmental Pollution and Health

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Department of Forestry and Environmental Science
School of Earth and Environmental Science

Uttarakhand Open University
Haldwani, Nainital (U.K.)

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Unit 1: Environmental Pollution: Definition; Historical development; Types and classification of pollutants; Scope of the study

Unit Structure

1.0. Learning objectives

After reading this unit we probably become able to:

- Describe environmental pollution
- Know about past historical pollution episodes/case studies and their cause
- Identify and enlist major types of agents (pollutants) deteriorating our environment
- Distinguish between air, water and soil pollution and their respective pollutants
- Be acquainted with biological accumulation and bio-magnification of toxic pollutants through food chain mechanism
- Know about sources and toxic effects of environmental pollution.

1.1 Introduction

Nowadays, man is facing several types of environmental stresses and ecological crisis among which environmental pollution is one of the major

problem. In this unit we will discuss about environmental pollution which is resulting in a number of calamities and harmfully affecting health of humans, plants and animals. Environmental contamination is attributed by means of any undesirable, unwanted and unpleasant physical, chemical and biological alterations within the environmental constituents i.e. air, water and soil majorly via anthropogenic activities. As the human population is growing drastically, there occurs a demand for enormous resources and technological advancement which ultimately lead to overexploitation of resources as well as degrading the quality of environment by generating a lot of wastes. Therefore, the absence of quality environment is the precursor of deteriorated or polluted environment.

1.2. Environmental pollution: definition

Environmental pollution is the inauspicious and undesirable physical, chemical or biological alterations in the physical, chemical and biological aspects of different environmental constituents namely air, water and land leading to deterioration of environment and makes it harmful for humans, other living organisms and various cultural assets. Scientifically, contamination of environment is termed as environmental pollution and the respective contaminating agents are called pollutants. However, it is not the wastes alone which deteriorate the environment quality. Sometimes, certain valuable materials may also pollute the environment due to overuse or misuse or mismanagement e.g., fertilizers improve the soil fertility but pollute soil due to overuse and pollute water due to misuse and mismanagement. Any constituent of environment weather biotic or abiotic may become pollutant if its concentration exceeds beyond the desired limits in the environment. Therefore, environmental pollution may also be defined as an addition of undesirable materials or excessive addition of useful materials in the environment beyond the threshold limits where the usefulness of that material is damaged and resulting in the degradation of environmental quality thereby making it unfit for life.

1.2.1 Historical development (Pollution case studies)

It is reasonably essential to be familiar with the historical events pertaining to environmental pollution in order to be aware of cause and effects of harmful pollutants and to prevent imminent tragedies. Major pollution case studies have been given below as in table 1:

1) London smog 2) Los Angeles smog 3) Bhopal gas tragedy 4) Chernobyl nuclear disaster 5) Fukushima nuclear disaster 6) Minamata Bay incident

Table 1: Major case studies related to environmental pollution

S. No.	Name of the event/ case study	Cause / pollutants involved	Impact	Place	Year of occurrence
1	London Smog	5 day Classical smog formed by condensation of water vapors with H_2S & SO_2 over dust particles at low temp.(-1^0 to -4^0C)	>50% population& vegetation affected, 4000 people killed	London (England)	5-11Dec, 1952
2	Los Angeles Smog	Photochemical smog formed by interaction of sunlight with major vehicular exhausts, NO & Hydrocarbons at 24^0 -32^0C	Thousands of people killed &biodiversity destroyed	Los Angeles (USA)	1943
3	Bhopal gas tragedy	Leakage of Methyl Isocyanate gas from Insecticide unit of Union Carbide	Killed over 2500 people	Bhopal (India)	2nd Dec, 1984
4	Chernobyl nuclear disaster	Radioactive leakage (Radioactive pollution)	>4000 deaths and other sufferings	Ukraine (Russia)	26th April 1986
5	Fukushima nuclear disaster	Nuclear accident due to hydrogen and radioactive materials leakage sparked by earthquake and Tsunami	>1000 people died & other sufferings	Fukushima (Japan)	11th Mar, 2011
6	Minamata Bay incident	Minamata disease from mercury poisoning through eating mercury contaminated fish living in Minamata Bay	>900 deaths >3000 people suffered	Kyushu island (Japan)	1956

1.3 Classification of Pollutants

Pollutants can be described as the agents or materials which on addition into the environment responsible for making it unfit for life by deteriorating the environment quality. These may also be any useful substances or energies available in the environment but in excess limits or in harmful concentrations. Pollutants can be classified as per different criteria into following types discussed below:

1.3.1 On the basis of environment/medium in which they occurs

Environment comprised of three different mediums i.e. air, water and soil, which directly affect life in several ways by providing basic necessities of life to man and other living creatures on this earth. Therefore, pollutants responsible for any alteration in these mediums are divided into three respective categories as follows:

1) Air pollutants

Substances which get released in the atmosphere or air or whose concentration in the air alters air composition up to undesirable limits are referred to air pollutants. These are responsible for making the air dirty and harmful for all living organisms and damaging cultural assets. These are of three kinds: Gaseous pollutants (e.g. CO, CO2, NO, NO2, SO2, SO3, VOCs, etc.), Particulate pollutants (e.g. dust, smoke, aerosols, mist, fume, smog, pollens, spores, etc.), Radioactive pollutants (e.g. nuclear explosives during war like lead, uranium, etc.).

2) Water pollutants

Any foreign substances organic or inorganic or biological or radiological in nature having ability to change physical and chemical characteristics of water on their addition resulting health hazards for the living organisms are termed as water pollutant. There are three kinds of water pollutants: Physical pollutants (heat and oil spills), Chemical pollutants (Organic pollutants like DDT, BHC, PCBs, inorganic pollutants like Pb, Hg, Ar, Cd, Ni, P, fluorides, nitrites, etc.) and Biological pollutants (bacteria, viruses, protozoa, algae, etc.).

3) Soil/land pollutants

Substances which on addition into the soil are responsible for reduction in the soil fertility and productivity by altering soil property are called soil pollutants. These pollutants may include toxic chemical pollutants like Cu, Zn, Cd, Al, Fe, Pb, Hg, tin, acids, cyanides, alkalies, etc., pesticides like aldrin, dieldrin, endrin, malathion, parathion, DDT, etc., fungicides, weedicides, fertilizers, etc.).

1.3.2 On the basis of their persistence in the environment

Different environmental pollutants responsible for destruction of environmental quality when released into the environment from their sources persist in the environment in two different forms as:

1) Primary Pollutants

Pollutants which remain throughout in the form in which they are added to the environment are called as primary pollutants. Example: Plastics, etc.

2) Secondary pollutants

Primary pollutants interact with each other and results in the formation of new pollutants synergistically called secondary pollutants. Synergistically or synergism refers to combining two or more less toxic components to form two times much toxic compound Example: Ozone (O_3), Peroxyacyl nitrate (PAN). These have more toxic effect that their parent molecules or primary pollutants.

1.3.3 On the basis of their existence in the nature

According to the occurrence of pollutants in the nature, they may be classified into two types as:

1) Quantitative pollutants

These include those substances which are present and occur naturally in the environment before the origin of man on this earth and also added by man but in large quantities. Example: Carbon dioxide (CO2) is always present in the environment and also added by man through breathing and other activities like burning fire, emissions from industries and automobiles.

2) Qualitative pollutants

These include those substances which normally do not occur in nature but are added by man anthropogenically. Example: insecticides, pesticides, herbicides, weedicides, fertilizers, etc.

1.3.4 On the basis of natural disposal

Depending upon their degradability and mode of elimination from the environment, pollutants may be categorized into two following groups:

1) Biodegradable pollutants

Pollutants or contaminating substances which can naturally be decomposed quickly by microbial action or other biological action like radiation are termed as biodegradable pollutants. These are generally organic in nature. Example: sewage responsible for water pollution (microbial degradation), Heat responsible for thermal pollution (degradation via loss of Radiations).

2) Non-biodegradable pollutants

Substances which do not be degrade naturally or are degrade very slowly are termed as non-biodegradable pollutants. These are generally inorganic in nature and tend to pass through food chain and get bioaccumulate and biomagnify in the living tissues.Example: inorganic pesticides like DDT, heavy metals, plastics, glass, radioactive materials, etc**.**

1.4 Types of Environmental pollution/pollutants

Generally environment comprises air, water and soil, therefore, environmental pollution associated with its components is of three major types:

- Air/atmospheric Pollution
- Water Pollution
- Soil/land Pollution

In addition to these, there are two other types of pollution having severe impact on environment and living organisms. These are:

- Noise Pollution
- Radioactive Pollution

1.4.1 Air Pollution and air pollutants

Air is a mixture of different constituents of specific concentration comprising 78% Nitrogen, 21% Oxygen, 0.04% Carbon dioxide and rest other gases in very low concentration. Any significant alteration in normal composition of air due to introduction of any foreign substance indicates air pollution posing a serious threat on the well being of all living organisms, environment and property. Therefore, air pollution could be understood as introduction of any foreign, undesirable and unwanted physical, chemical biological materials in the atmosphere in such concentrations that prove fatal for humans, plants and animals and also damage property and further contribute to climate change. Such polluting agents or materials that contribute to air or atmospheric pollution are termed as air pollutants.

Causes of Air pollution

There are two major causes contributing air pollution: Natural Cause and Anthropogenic cause. Natural cause of air pollution includes forest fires, volcanic eruptions, dust storms, natural organic and inorganic decays that produce harmful gases like sulphur oxides, methane gas, etc., dust particles, ashes, etc. Natural pollutants also comprised of spores, bacteria, viruses, pollens, etc. While anthropogenic cause includes air pollutants released into the atmosphere through various human activities. With the rapid growth in human population, demand for energy and resources to make better livelihood has also been increased. With the advent of industrialization, invention of automobiles and other developments to meet the rising demands of growing population, deterioration of air quality has also been speeded up. Emissions from industries, fireworks, nuclear explosions and many other human activities are the major forces behind anthropogenic air pollution.

1.4.2 Water Pollution and water pollutants

Water especially pure water is the potent and vital necessity for life without which life would be impossible. Alteration of physical, chemical and biological characteristics of water due occurrence of any foreign material in the water that results in degradation of water quality and seriously affecting

the well being of humans, plants and animals is termed as water pollution. These materials responsible for polluting water are called water pollutants.

Causes of water pollution

There are also two reasons behind the pollution of water: Natural and Anthropogenic. Natural causes of polluting the water include soil erosion and rock weathering through which soil particles and rock minerals respectively get dissolved in water bodies and pollute them. Fall of dead fallen leaves and decaying of fallen leaves and other organic matter in the water bodies also deteriorates water quality. Anthropogenic or man-made causes of water pollution include human activities which lead to discharge of various organic wastes like, industrial effluents, domestic waste, sewage, animal waste, waste from slaughter houses, etc., inorganic chemicals like pesticides, fertilizers, etc., agricultural runoffs, oil spills, heat and radioactive wastes into water bodies.

1.4.3 Soil/land Pollution and soil pollutants

Soil is the topmost layer of land or earth's surface and supports plant life, which, in turn, supports animal life including humans. Humans also interact directly or indirectly with soil as it nurtures life by providing indispensable provisions to life such as foodstuff, shelter and also clothing from plants and animals which directly and indirectly depends on soil. Therefore, any change in soil composition due to presence of any foreign and harmful substance in the soil may affect all organisms. Such alteration in soil due to addition of foreign materials leading to reduced productivity and decreased fertility is termed as soil or land pollution and the respective polluting materials are called as soil pollutants.

Causes of soil pollution

There are natural as well as manmade causes of soil pollution. Natural causes include floods containing contaminated water, acid rain, mineral deposition via rainwater flow from weathering of rocks, etc while manmade causes include a variety effluents and run offs that finally reach the soil directly with water or indirectly through air which further contribute to acid rain and

ultimately reach the soil. These effluents may include various chemicals, pesticides, fertilizers, discarded materials, radioactive wastes, etc.

1.4.4 Noise Pollution

Sound is the only requisite and essential medium of communication in humans and other animals. But, if the sound becomes unpleasant, loud, disturbing, annoying, harmful, unwanted, cause stress or impair the hearing ability than it is called noise. Such persistent, disturbing, often excessive level of noise causing harmful effects in the environment from various sources like automobile horns, industries, loud speakers, etc is termed as noise pollution. This kind of physical pollution affects man directly to large extent than other living organisms also without affecting life-supporting systems called environmental components i.e. air/atmosphere, water and land.

Causes of Noise pollution

Noise pollution is completely contributed by manmade activities through various activities that produce annoying, loud and harmful sound called noise. Major activities include construction, blowing horns of transport vehicles, running machines in various industries, using domestic gadgets, entertainment equipments and many more.

1.4.5 Radioactive Pollution

Radioactive pollution is associated with radioactive substances which create physical pollution of air, water and soil on introduction to them. Radioactive material or substance are certain kind of elements e.g. Uranium, Radium, etc. that give off harmful radiations (protons or alpha particles, electrons or beta particles and gamma radiations) simultaneously on disintegration of their atomic nuclei. Therefore, radioactive pollution can be defined as the introduction of any radioactive material into physical environment or environmental components leading to very disrupting impact on life on earth.

Cause of Radioactive pollution

Radioactive pollution occurs due to release of radioactive substances or radiations into the environment due to any nuclear explosion or release of the

radioactive waste generated from nuclear power plants, and other naturally occurring radioactive elements present in earth crust, like Radium-224, Uranium-235, Thorium-232, radon-222 and potassium-40, etc. into the environment.

1.5 Sources and effects of environmental pollution/pollutants

In this section we will discuss about sources and effects of different environmental pollution or pollutants such as air pollutants, water pollutants, soil pollutants, noise pollutants and radioactive pollutants.

1.5.1 Sources and effects of air pollution

Major sources of air pollution include fossil fuels combustion in automobiles and industries which give off emissions containing unburned hydrocarbons, lead, carbonacious, nitrogenous and sulphurous compounds that may cause severe impact on environment quality as well as health damaging effect on living organisms.

Sources of air pollution

There are four main sources of air pollution which contribute emission of air pollutants into the environment:

1) Point or Stationary Sources: These include sources which introduce or emit pollutants into the atmosphere from specified points through chimneys**.** Example: Industries, thermal power plants, etc.

2) Line or Mobile Source: These include sources which add pollutants into the atmosphere along narrow belts (i.e. roads) over long distances. Example: smoke coming out from automobile exhausts, etc.

3) Area source: These include sources which add pollutants from the fire over wide areas. Example: Industrial estates and mining area, etc.

4) Diffuse source: These include sources which spread pollutants over a large area through spraying or diffusion. Example: sprayed fertilizers and pesticides spread over a large areas through runoff.

Major air pollutants, their sources and effect: Air pollutants are of three kinds:

Gaseous pollutants: include oxides of Nitrogen i.e. NO, NO_2, oxides of Carbon i.e. CO, CO_2 and oxides of Sulphur i.e. SO_2, SO_3, hydrocarbons, photochemical oxidants (Peroxyacyl nitrate, Ozone, Smog), Fluorides, aldehydes, peroxides,etc.

Particulate pollutants: include dust, smoke, aerosols, mist, fume, smog, pollens, spores, etc. **Radioactive pollutants:** include nuclear explosives during war like lead, uranium, etc. These sources and their effects can be illustrated from the below table 2.

Table 2: Major air pollutants, their sources and effects

Air pollutants	Sources	Effects on humans & animals	Effects on plants, environment & material, if any
Carbon monoxide (CO)	Cigarette Smoking, vehicular exhausts, incomplete burning/combustion	Reduces oxygen carrying capacity of blood may cause death, poisoning, giddiness, reduced vision, nervous &cardiovascular disorders, etc.	Generally no serious impact on plants, environment & material
Carbon dioxide (CO_2)	Respiration, decay, biomass burning, smoking, automobile/ coal & petroleum combustion, etc.	Nausea, headache,	Green house effect that produces carbonic acid & resulting acid rain damaging

			plant cells, buildings, monuments
Nitrogen oxides	Burning/combustion of fuels & biomass, lightening, etc.	Reduces oxygen carrying capacity of blood, irritation of eyes, nose, respiratory epithelium,	Form PAN and acid rain which suppresses plant growth, also causes leaf necrosis and defoliation in plants. Spoil metal & clothes also
Sulphur oxides	Combustion of fuels, petroleum refining, metal ore smelting, H_2S, incineration, etc.	Drying of mouth, sore throat, irritation in eyes, respiratory tract, lungs, respiratory diseases, etc.	Causes acid rain, damage to clothes, corrosion of paints & metals. Also injurious to plant cells causes chlorosis, plasmolysis, membrane damage, metabolic inhibition may lead to plant death
Hydrocarbons	Decay of sewage, landfills, incomplete combustion of fuels, biomass, etc.	Carcinogenic effect	Senescence and abscission in plants

Peroxycayl nitrate (PAN)	Photochemical interaction among nitrogen oxides & hydrocarbons present in the air in presence of sunlight	Irritating sensation or pain in eyes, nasal passage, throat, respiratory tract, respiratory diseases	Produces haze, blocking of sunlight resulting reduction in plant photosynthesis, damage leafy vegetables
Ozone (O_3)	Photochemical interaction among nitrogen oxides & hydrocarbons present in the air in presence of UV rays	Chest pain, coughing, eye irritation,	Premature yellowing of leaves, fall of leaves, decolouration & disinte- gration of clothes, damages rubber, tyres
Aldehydes	Photochemical interaction among nitrogen oxides & hydrocarbons present in the air in presence of sunlight	Irritating sensation or pain in gastrointestinal & respi-ratory tracts	Decoloration of leaves & damaging of clothes
Fluorides	Steel, aluminium, phosphate fertilizer industries, coal burning,	Fluorosis (spotting of teeth), brittle bones & uneven teeth development due to eating & grazing fluoride contaminated	Delays crop maturing & reduces fruit yield due to fluoride accumulation in leaf stomata. Also atack glass, paints & metal

		plants & grasses	surfaces
Dusts	Construction, stone crushing, industrial processes, forest fires, coal burning, etc.	Lung fibrosis (asbestosis, silicosis, byssinosis), lead poisoning, & other respiratory diseases	Blocking of sunlight retards plant photosynthesis
Polychlorinated biphenyls	Burning of plastics	Damage liver & central nervous system, impair vision, skin pigment alteration.	
Pollens, spores, bacteria, viruses	Living organisms & their components	Allergies, respiratory diseases, hay fever & other diseases	Remain suspended in the air & block sunlight, etc.
Smog	Dust + smoke or Smoke + Fog	Toxic to all organisms,	Destruction of vegetation, rubber cracking, etc
Radioactive pollutants	Nuclear explosions	Death of living cells due to DNA rupturing resulting death of organisms	Death of plant cells and tissues, disintegration of metals, clothes, building materials, etc.

Acid rain: a product of air pollution

The term acid rain was first coined by Robert August in 1872. Acid rain formation takes place naturally but initiated by manmade activities that lead to the emission of major pollutants like oxides of sulphur and oxides of nitrogen.

Normally, rain water has pH of acidic range i.e. 5.6-6.5. Thus, acid rain may be defined as the precipitation with pH less than 5. It is generally made up of sulphuric acid and nitric acid formed in the atmosphere from sulphurous and nitrogenous compounds respectively by oxidation. The process of formation of acid rain can be illustrated through fig.1. Major sources of nitrogenous compounds or oxides may include emissions from fossil fuel combustors, lightening, automobile exhausts, etc. and that of sulphur containing oxides include smelters, power plants domestic fires, biomass burning etc. From different sources various sulphur and nitrogen containing compounds or sometimes their respective oxides released into the atmosphere and further undergo atmospheric oxidation to form higher oxides. These oxides are changed into sulphuric acid (H_2SO_4) and nitric acid (HNO_3) on combination with water vapors present in the atmosphere and ammonium sulphate and ammonium nitrates aerosols on combination with ammonia (NH_3). These aerosols may acts as cloud condensation nuclei (CCN) which are responsible for cloud formation and precipitation.

From the atmosphere, these acids or acidic sulphur and nitrogen oxides deposit over earth in two distinct forms: Dry deposition and Wet deposition. Dry deposition takes place by settling down of windblown acid oxides and other particles in dry state while Wet deposition on earth occurs in the form of rain called acid rain, fog or snow.

Effects: Acid rain causes soil acidity that severely affects terrestrial flora and fauna inhabited in it. It may also lead to contamination of water bodies present on land that further affect aquatic flora and fauna. Terrestrial plants also get affected directly from acid rain and indirectly from soil contaminated with acid rain and produces symptoms like defoliation, necrosis, chlorosis, etc. Acid rain is also responsible for damaging building materials like stones, slate and corroding metals, painted surfaces, marbles, and monuments like Taj Mahal at Agra due to acid deposition.

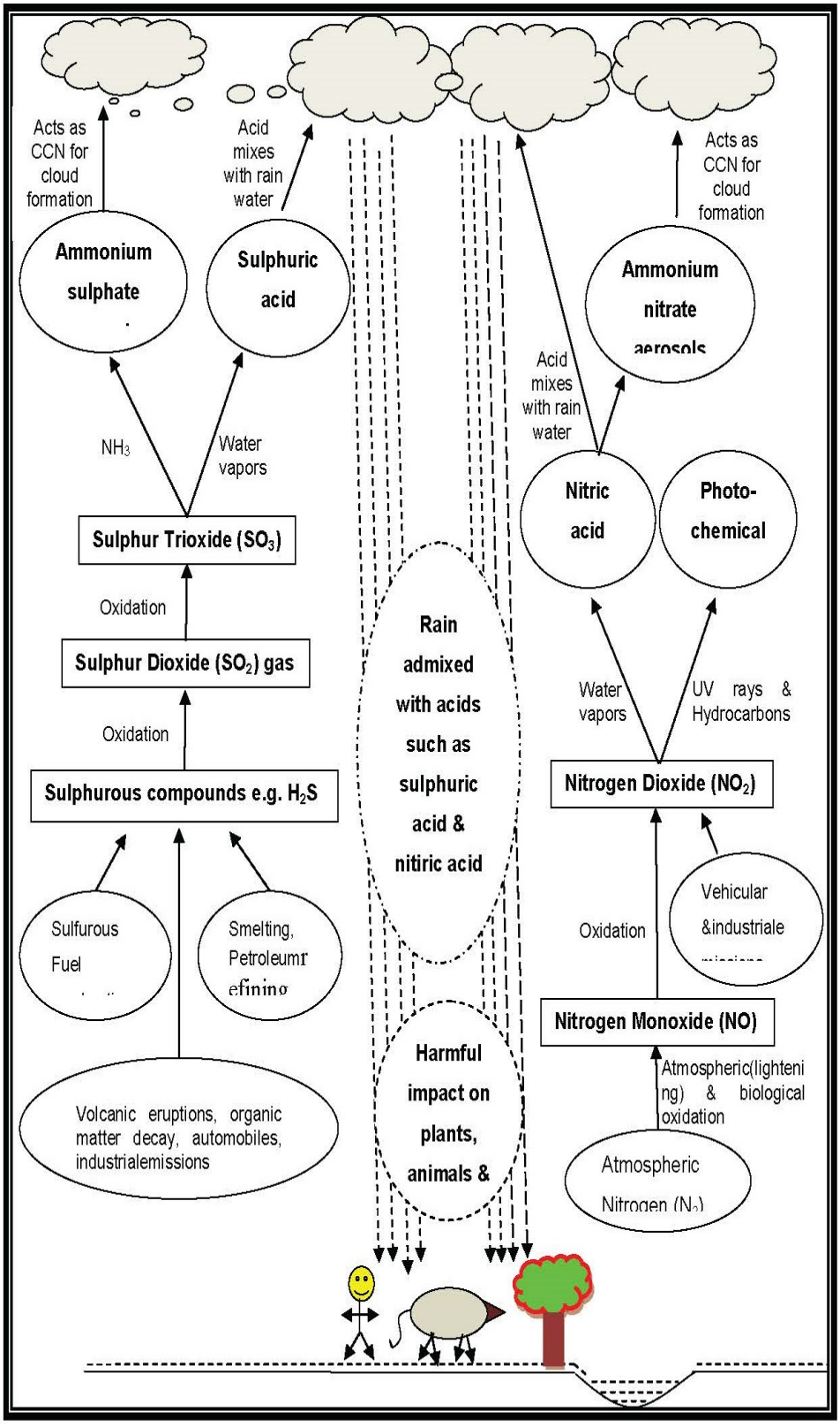

Figure 1: Formation of acid rain in the atmosphere.

Check your progress: Self-Assessment Questions (SAQ)

Q1. Which of the following is a gaseous air pollutant? A) Fume B) Smog C) PAN D) Uranium.

Q2. What is the pH of acid rain? A) 6 B) 5.5-6.5 C) Above 7 D) below 5.

Q3. Bhopal gas tragedy resulted due to leakage of _____ gas.

Q4. Secondary pollutants formed due to interaction of _____.

Q5. Premature yellowing of leaves in plants caused by ____.

1.5.2 Sources and effects of water pollution

Water pollution is not only confined to surface water, but it has also spread to underground and sea water to a greater or lesser extent.

Sources of water pollution:

Depending upon pollutants discharge into water bodies, there are two types of water pollution sources:

1) Point sources: involve pollutants discharge directly from a definite source through the regular channels i.e. municipal and industrial discharge pipes to water bodies.

2) Diffuse/non-point sources: involves discharge of pollutants like pesticides, fertilizers scattered on the ground from undefined and diffuse sources into the water bodies through runoffs, etc.

Determination of water quality: water quality can be determined by three major parameters i.e DO, BOD and COD describes below in table 3.

Depending upon the nature and producers of pollutants, there are six types of water pollution sources:

1) **Sewerage/Community waste water:**It comprised of domestic and commercial waste discharge in the form of sewerage emitted into public sewerage systems. Example: human and animal excreta, soaps, detergents, food wastes and many more.

Table 3: Major parameters for water quality determination

Parameter	Definition	Concentration value for unpolluted water
DO (Dissolved Oxygen)	Amount of oxygen content dissolved in water	> 8.0 mgL^{-1}
BOD (Biological Oxygen Demand)	Amount of oxygen content needed by bacteria to decompose organic matter present in water	< 4.0 mgL^{-1}
COD (Chemical Oxygen Demand)	Amount of oxygen content requisiteto oxidize total organic matter (biodegradable & non-biodegradable) present in water	< 5.0 mgL^{-1}

2) Industrial wastes: It includes waste or effluents generated and discharged off from different kinds of industries given in table 4.

Table 4: Sources of water pollutants from industrial waste

Types of industry	Inorganic pollutants, if any	Organic pollutants, if any
Paper & pulp	Sulphides, bleaching liquors	Cellulose fibres, berk, wood sugars, organic acids
Mining	Various metals like iron, etc and their Chlorides, sulphates, hydroxides, H_2S, heavy metals, surface wash offs, suspended solids, sulphuric acids, etc.	Not defined
Iron and steel	Various oxides of metals like copper, mercury, cadmium, chromium, sulphides, iron cyanides, thiocyanates, suspended solids, etc.	Oil, naphthalenes, phenols, etc.
Soap & Detergents	Alkalies, tertiary ammonium compounds, etc.	Higher fatty acids, fats, sulphonated hydrocarbons, glycerols, polyphosphates, etc.
Chemical plants	Various acids, alkalies, metal chlorides, sulphates, nitrates, fluorine, phosphorus, silica, suspended particles, etc.	Organic solvants and acids, aromatic compounds, nitro compound dyes, etc.

Food processing	Not defined	Extremely decomposable organic matter, pathogens, etc.
Pharmaceuticals	Not defined	Drugs, antibiotics, organic solvants, proteins, carbohydrates, vitamins, etc.

3) Agricultural sources: These consist of agricultural run offs and drainages containing fertilizers (constituting Nitrogen, Phosphorus and Potassium), pesticides (insecticides, weedicides, fungicides, herbicides, rodenticides, soil fumigants, etc.

4) Thermal pollution or heat: Major sources include thermal and nuclear power plants where water is used as coolant and produce hot water. Discharge of this high temperature water into the water bodies may kill aquatic life prevailing there.

5) Ground water pollution: Seepage or leaching of various effluents and contaminants like industrial and municipal waste, sewage channels, agricultural runoffs, etc. pollute ground water posing a serious threat to availability of pure drinking water.

6**) Marine/ sea water pollution:** Oceans and seas are the natural sink of all variety of pollutants generated on this earth including even rivers that discharge their pollutants into oceans. These pollutants may be any radioactive waste, plastics, garbage, oil, grease, detergents, sewage, and many more.

Effects of water pollution: Water polluting contaminants alter the physical, chemical and biological characteristics of water resulting into following effects:-

- Water pollution results in the scarcity of pure, clean and fresh drinking water. It also make water unsafe and unfit for domestic and other purposes due to addition of soaps, dyes, detergents, chemicals, heavy metals and other impurities in it.
- Drinking of polluted water may result in various health disorders and can spread many diseases. For example, drinking of water contaminated with poisonous chemicals like cadmium, arsenic, mercury, nitrates, fluorides, etc. lead to many sufferings among living

organisms. Contamination of Cadmium causes **itai-itai** disease (also called ouch-ouch disease) which is an aching illness of bones and joints, also cause liver and lung cancers. Arsenic poisoning may lead to **black foot diseases** with symptoms like diarrhea, peripheral neuritis, resulting in skin and lung cancers. Mercury poisoning leads to its conversion by bacteria into methyl mercury that undergo biomagnification through food chain and leads to deformity called **Minamata disease** causing diarrhea, impairment of senses, hemolysis, meningitis and even death also. Nitrate pollution proves lethal for infants causes **blue-baby syndrome or methaemoglobinemia** that impairs oxygen supply. Fluoride may result **fluorosis** that causes dental problems and dysfunctioning of respiratory, neuromuscular, gastrointestinal systems.

- Eutrophication: Plant nutrients like nitrogen, phosphorus, potassium, etc discharge off into water bodies leading to growth of oxygen consuming algal population over the water surface, which deoxygenate water and results in the killing of aquatic organisms thriving there.

1.5.3 Sources and effects of soil/land pollution

Soil pollution involves a variety of sources that add soil pollutants into soil. These sources are described below in the table 5.

Table 5: Major sources of soil pollution

Sources	Soil pollutants
Industrial wastes	Chemicals like lead, mercury, copper, zinc, cadmium, cyanides, organic compounds, acids, alkalies, chromates, etc.
Pesticides	Insecticides, herbicides, rodenticides, weedicides, algaecides, fungicides
Fertilizers	NPK fertilizers, urea, manures, etc.
Discarded materials	Concrete, paper, food waste, plastics, glass, cans, carcasses, etc.
Radioactive wastes	Radioactive elements like uranium, thorium, radium, etc.
Other pollutants	Acid rain formed from major air pollutants like NO_2, SO_2, etc.

Effects of soil pollution: Soil affects drastically each and every component on the earth as it supports life and feeds every organism. Humans, plants and animals depend solely on soil for maintaining their livelihood and obtaining food from it. Therefore, any alteration in soil characteristics by introducing above said pollutants may causes many severe impacts as given below:

- Agricultural impacts: Soil pollution may results reduction in soil fertility and productivity, decrease in nitrogen fixation ability of soil, increase in soil erosion and loss of fertile land, loss of soil nutrients reduction in crop yield, increase in soil salinity, acidity or alkalinity, etc.
- Health impacts: Absorption of toxic contaminants by plants resulting plants health damage and then transfer into human and other animals via food chain creating severe toxicity among them also. Release of toxic gases and dangerous chemicals from polluted soil into air and ground water may cause many health disorders.
- Environmental impacts: Soil pollution may disrupt ecological balance by reducing vegetation growth and may also cause imbalance in soil fauna and flora.
- Other impacts: Waste management problems, foul smell due to release of gases, inundation of areas, clogging of drains, etc.

1.5.4 Sources and effects of noise pollution

Sources of noise pollution: Noise pollution is mainly created by annoying, unpleasant and damaging sound producing machines, equipments, instruments, etc. There are following sources of noise pollution:-Industries, transport or automobile vehicles, defence equipments, space rockets, domestic gadgets, entertainment systems, public address systems, music concerts, construction works, fire crackers, and many more.

Effects of sound pollution: Noise is measured in decibels (dB). Every 10dB is equivalent to double the increase in loudness. World Health Organization recommended that sound level of <30dB is safe for indoors. Any increase in prescribed sound level results in various impacts as:

- Create annoyance among people which may badly affect their mood swings

- Continuous exposure to high sound levels can affects physiological functioning like pulse rate, breathing amplitude, blood pressure, heart-beat rate, blood cholesterol, etc.
- Continuous and prolonged exposure to sound level >75dB may result loss of hearing
- High level noise distracts concentration of a person and affects his performance also
- On exposure to infrasonic and ultrasonic waves, building and materials may get collapsed and destroyed
- High level noise makes person sleepless, restless, also pain and ringing in ears, feeling of tiredness.

1.5.5 Sources and effects of radioactive pollution

Sources: Radioactive pollution occurs due to the contamination of air, water or soil with radioactive material. Radioactive materials produce harmful radiations and may cause huge damage to life. Radioactive pollution has two sources: Natural and manmade. Natural source include outer space cosmic rays that reach the earth surface, terrestrial radiations from nuclides of naturally occurring radioactive elements such as Uranium-235, Radon-222, Thorium-232, Radium-224, etc. These have not so much hazardous as present in very low concentration. On the other hand, manmade sources of radioactive pollution include mining and refining of radioactive elements like plutonium and thorium, nuclear explosions consisting Strontium-90, Cesium-137 and Iodine-131, waste from atomic and nuclear reactors, nuclear fuel, radioactive isotopes manufacturing like Carbon-14, Iodine-125, Phosphorus-32, etc.,

Effects: The effect of radioactive material depends upon certain factors like the intensity of radiation, rate of diffusion, radiation exposure time duration and half life of material. Greater is the value for these factors greater is the impact. Major impacts of radioactive pollution are:

- Short range effects which appear within few days or weeks after exposure to these radiating materials include burns, hair loss, impaired metabolism, alteration in number and proportion of blood corpuscles, death of cells, tissues or whole organism.

- Long range effects that appear months or years or even in next generations after exposure to radioactive materials radiations include genetic mutations, cancers, tumors, early deaths, embryo developmental changes, etc.
- Strontium-90 can cause bone cancer due to accumulation in bones. Iodine-131 can damage blood corpuscles, bone marrow, spleen , lymphatic system and also lead to skin cancer, lung cancer, loss of fertility, loss of eyesight and many other impacts.

1.6 Summary

In this unit, we have read about the concept of environmental pollution and their corresponding pollutants. So far you have learnt that:

- Environmental pollution is the contamination of environmental components i.e. air, water and soil by natural (lesser extent) as well as manmade activities (greater extent).
- Emission of toxic/harmful materials into air results air pollution and the corresponding materials called air pollutants that comprised of gaseous materials, particulate matter and radioactive substances (see text for detailed understanding).
- Release of harmful substances from various sources (described in text) into water bodies causes water pollutant and the respective substances called water pollutants that may include organic compounds, pathogens, toxic chemicals, dust, heavy metals and many more.
- Release of effluents and toxic materials from industries, agricultural runoffs and domestic waste, etc. into soil or land leads to soil pollution and the effluents and material called soil pollutants.
- Noise pollution is the result of loud, unpleasant, disturbingand damaging sound. Noise greater than 75 decibel may result loss of hearing.
- Radioactive pollution occurs due to harmful emissions given off by radioactive materials present on the earth naturally or by manmade activities.

- All kinds of environmental pollution may bring havoc by through their damaging effects. For instance air pollution can cause several respiratory and other diseases among humans, many health effects among plants and damaging affect on material or cultural assets. While water pollution may lead several diseases like fluorosis, blue-baby syndrome, minamata disease and many more among humans, also affect plants health, results eutrophication that degrade aquatic life in waterbodies, etc. Soil pollution also impart its impacts on living organisms through transfer of pollutants via food chain.
- Noise pollution also have the ability to affects living being as well as buildings and materials severely. While radioactive pollution can damage living cells and tissues and often cause death of organisms.

1.7 Glossary

Abiotic:	Non-living components present in the environment
Acid rain:	Rain admixed with acids produced in the atmosphere from air pollutants and water vapors and having pH less than 5
Anthropogenic activities:	Man-made activities
Biotic:	Living components present in the environment
Environment:	The sum total of living and non-living components present in the surroundings
Environmental pollution:	Alterations in the environmental characteristics by addition of harmful materials into the environment
Food Chain:	Linear sequence of organisms linked together for food where an organism becomes food for organism at next trophic level
PAN:	Peroxyacyl nitrate formed by the Photochemical interactions among nitrogen oxides & hydrocarbons present in the air in presence in presence of sunlight

1.8 Answer to check your progress/Possible Answers to SAQ

Q1. C) PAN (Peroxyacyl Nitrate)

Q2. D) below 5

Q3. Methyl Icocyanate

Q4. Primary pollutants

Q5. Ozone (O_3)

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1.11 Terminal and Model Questions

Q1. Differentiate between qualitative and quantitative pollutants.

Q2. Discuss major gaseous pollutants, their sources and impact on human health.

Q3. Briefly describe various diseases among humans caused by water pollution.

Q4. Explain the process of formation of acid rain.

Q5. Air, water and radioactive pollutants contribute to soil pollution. How?

Q6. What are the major effects of noise pollution?

Unit 2: Air Pollution

Unit Structure

2.0. Learning objectives

After reading the chapter, you shall be able to:

- ✓ Define air pollution and describe different types of air pollutants
- ✓ Classify various air pollutants on various aspects
- ✓ Differentiate between indoor and outdoor air pollutants
- ✓ Describe importance of meteorological conditions in defining fate of air pollutant
- ✓ Explain the types, nature and behavior of air pollutants under the influence of atmospheric conditions.

2.1. Introduction

We can go without food and water for a few days, but we can't live without air for more than a few minutes. This basic fact demonstrates the importance of clean and pure air to us. However, numerous anthropogenic activities resulted in a change in composition of air and the microclimate of the surrounding environment. This undesirable change seems to be the most thoughtful threats

to the environment, affecting everything from humans to livestock to crops, forests, aquatic ecosystems and even materials.

Recent unprecedented growth in urban areas, rapid industrialization and urbanization has added a massive number of sources of air pollutants. The emission generated from these sources are creating short as well as long term intense levels of outdoor air pollutants with significant health effects. The problems associated with the indoor environment are also gaining recognition, especially in low-income countries. The use of biomass fuel for cooking, construction and furnishing material of the buildings appears prime sources for indoor air pollutants.

In this unit we will consider different types of air pollutants, which originate from variable sources. The air pollutants undergo chemical interactions with constituents of air and other air pollutants to produce new pollutants. However, the fate of air pollutants is greatly influenced by air mass and meteorological conditions. The concentrations of air pollutants will build-up at a location with calm and stable air mass. On the other hand, it disperses quickly with turbulent air mass and reduces the impacts associated with the air pollutants. The meteorological data has also a great importance also in identification of pollutants' sources, prediction of their behavior and hence in defining air quality in the surrounding area.

A study of this unit will help you to understand different type and classification of air pollutants on different aspects, indoor and outdoor air pollutants and influence of meteorological condition in defining the air quality in surrounding area.

2.2. Overview

Air pollution is described as the pollution in the environment by gaseous, liquid, or solid materials or by-products that can adversely affect health and plant and animal welfare, as well as create unpleasant odours. Any undesirable change in quality of air that harmfully affects people's wellbeing is considered as air pollution. Air pollution in India affects millions of lives directly or indirectly. In the year 2020, India had 22 of the top 30 highly polluted cities in the world.

Fig.1 Air Pollution (Source- Google)

2.3. Sources

There are two types of sources for air pollution: Natural and Anthropogenic.

- **Natural Sources**

  a) *Terrestrial Ecosystems:* Aerobic and anaerobic decomposition are active sources of carbon compounds like carbon dioxide (CO_2) and methane (CH_4). Biological oxidations and reduction of inorganic nitrogen in soils result in nitrogen species such as nitric oxide (NO), and nitrous oxide (N_2O).

  b) *Aquatic Ecosystems:* At the surface of wetlands and oceans, a diversity of physical, chemical, and biological processes occur that affect the global cycle of a variety of organisms, including carbon, sulphur, nitrogen, and trace metals. The bacterial production of methane is the most critical emission mechanism in wetlands and anaerobic waterlogged soils. During biological activities of phytoplankton dimethyl sulphide (DMS) is produced, which then enters the atmosphere by the exchange between sea and atmosphere.

  c) *Forest Fires:* Nearly all fires are caused by humans. Lightning is commonly the precursor of naturally produced forest fires. Although carbon dioxide (CO_2) is the major product of forest fires. A large amount of particulates and trace gases are also produced, including the products of incomplete combustion like CO, non-methane volatile organic compounds (NMVOCs) and sulphur species.

d) *Volcanic and Tectonic activities:* Volcanoes emit a large amount of gases and ash particulate into the atmosphere. Volcanic emissions can emerge during both eruptions and long-lasting non-eruptive activity. Water vapour is the most common volcanic gas, accounting for 50-90% of total volcanic emissions. However, in comparison to the amount of water vapour in the atmosphere, this amount is insignificant. Sulphur dioxide (SO_2), Carbon dioxide (CO_2), hydrogen sulphur (H_2S) and other sulphur species, hydrogen chloride (HCl), and other halogen compounds are other important gases emitted by volcanic activities. In addition to gases, most volcanic plumes emit a significant number of aerosols.

e) *Lightening*: During thunderstorms, lightning induces extreme temperatures, which triggers chemical reactions. The atmosphere's active ingredients (nitrogen, oxygen, and water vapour) are experience these chemical reactions, resulting in the creation of different molecules. Nitric oxide (NO) is a compound element formed throughout lightning.

f) *Process of radioactive disintegration*- During the process of decomposition of radioactive elements, particles or energy is released. For example, radon gas is emitted from the ground through cracks during the natural decomposition of thorium and uranium in the crust of Earth and has the ability to aggregate in spaces.

- **Anthropogenic Emission Sources**

1. *Industrial energy production and use:* During the processing and usage of energy, combustion processes take place which is the chief human caused source of air pollutants. Carbon dioxide is generated throughout the combustion process. Furthermore, combustion produces a large number of by-products, which originates either from incomplete fuel oxidation (e.g. CO, hydrocarbons, aerosol particles etc.) or from the oxidation of non-combustible species present in the combustion

chamber (e.g., NO_x, SO_x etc.). Other pollutants released from industrial combustion include heavy metals, polycyclic aromatic hydrocarbons (PAH), polychlorinated dibenzo-dioxins and polychlorinated dibenzo-furans (PCDD/F), polychlorinated biphenyls (PCB) and hexachlorobenzene (HCB).

2. *Transport:* Another big cause of air pollution is transportation. Public transport on land, sea, and air consumes a lot of energy, and different elements are released into the air during fuel combustion. Throughout terrestrial transportation, the most vital impurities discharged by road automobiles are ozone predecessor complexes, (CO, NO_x, NMVOCs), greenhouse gases (CO_2, CH_4, N_2O), aerosol particles, heavy metals and other toxic substances. Air contaminants released by aircraft may have an effect on atmospheric procedures in both the permitted and inferior stratospheres. Water navigation causes emissions of CO_2, CH_4, N_2O as well as carbon monoxide (CO), NMVOCs, sulphur dioxide (SO_2), particulate matter (PM) and NO_x

3. *Agriculture:* Human-caused air pollution can also be released into the environment as a result of agronomic actions. Animal husbandry and compost administration are the primary bases of discharges. NH_3 and NO are released into the air as a result of these practices. Crop burning is another, less significant agronomic cause of air pollution. Ammonia (NH_3), sulphur dioxide (SO_2), non-methane volatile compounds (NMVOCs), nitrogen oxides (NO_x), heavy metals, carbon monoxide (CO), particulate matter (PM), and dioxins are all discharged into the environment as a result of these processes.

4. *Biomass Burning:* Open and domestic biomass burning contribute 25% of global yearly CO releases, 18% of NO_x releases, and 6% of non-methane volatile organic compounds (NMVOCs) and CH_4 releases (Intergovernmental Panel on Climate Change (IPCC), 2001).

5. *Development and destruction activities*– The process of construction, establishment and demolition of buildings leads to the release of

pollutants. Various construction materials are potential air pollutants. Asbestos, PCBs and PBDEs are released from the destruction of old buildings.

6. *Building Heating* – Different techniques like boiler and furnace are used to increase the temperature of buildings which leads to the release of particulate matter and gases due to combustion of fuels used in them.

7. *Process of disposal of landfills*– Waste buried in landfills decomposes by natural decaying process of microbes which leads to the production of methane gas.

8. *Prescribed burning in forest and agriculture management* – It is the process of management of controlled and planned burning to maintain the health of forest and plants. But it reduces the quality of air by emission of particulate matter and gases.

9. *Military activities* – Military activities and war introduce large amount of Greenhouse gases (GHG) and affect the environment during training and practicing.

10. *Smoking* – During the process of smoking, inhale and exhale of fumes of burning material like cigarette takes place which release a large amount of toxic and carcinogenic chemicals.

11. *Deposition and use of household products* - Sprays, dyes, paint and varnish, etc evaporates in air and release organic solvents.

12. *Dry cleaning* - Dry cleaned clothes cause indoor pollution when stored enclosed and emit PCE (Chlorinated solvents petroleum solvents) etc which leads to health risk.

2.4. Types of Air Pollution

There are two types of air pollution;

i. Indoor air pollution
ii. Outdoor air pollution

Indoor air pollution:

Indoor air pollution is the presence of undesirable component in the indoor air that deteriorates its quality and disturbs its natural composition and chemistry. Indoor air pollutants include carbon monoxide, VOCs, tobacco smoke, asbestos, lead, radon and indoor particulate matter. Most victims are women, children and factory workers.

Outdoor air pollution:

Outdoor air pollution is demarcated as the adulteration of outdoor air by natural and man-made sources. It affects the human health as it consists of mixture of gases and particles. The sources include power plants, vehicle emissions, domestic heating etc. Pollutants generated from these sources have many adverse impacts on human beings like asthma, respiratory problems, circulatory problems, eye irritation etc. E.g., NO_x, SO_x, PAN, ozone, particulate matter constitutes outdoor air pollution.

2.5. What is an Air Pollutant?

Only when a substance's concentration is substantially higher than its actual levels and induces detrimental impacts will it be labelled as an air pollutant. There are basically two physical forms of air pollutants. The first one is the gaseous pollutants like ozone, sulphur dioxide, methane etc. The other form is particulate matter which includes microscopic solid or liquid particles suspended in air like dust, soot, fumes etc.

There are many methods of classifying air pollutants:

1) **Based on the source of origin**

a) *Natural air pollutants*: Volcanic activity, dust, sea-salt, forest fires, lightning, soil out gassing, and other natural causes release natural air contaminants.

b) *Anthropogenic air pollutants*: The Contaminants comprise pollution from immobile point sources (such as industries), mobile sources (such as vehicular emissions, marine vessels, aircraft, and so on), waste management landfills, and regulated burning, among others.

2) Based on the method of origin

a) *Primary air pollutants*- Impurities that are straight released from a source and stay in the air in almost the same chemical form as when they were generated from the source are referred to as primary pollutant. Sulphur dioxide, nitric oxide, nitrogen dioxide, and other gases are examples.

b) *Secondary air pollutants*- Secondary contaminants are created when two and sometimes more primary pollutants combine to form a new component that has a negative impact on the environment. For example, ozone (O_3) and peroxyacetyl nitrate (PAN).

3) Based on chemical composition

a) *Organic air pollutants*: Hydrocarbons, alcohols, ketones, aldehydes, and amines are some examples.

b) *Inorganic air pollutants*: Carbon compounds (CO and carbonates), halogen compounds (HF, HCl, etc.), sulphur compounds (H_2S, SO_2, SO_3, H_2SO_4), nitrogen compounds (NO_X and NH_3), fly ash, silicon oxide, and other materials are some examples.

4) Based on state of matter

a) *Gaseous air pollutants*: Gaseous air contaminants are pollutants that are in the form of gas. For example, NO_X, SO_2, CO, O_3, and so on.

b) Particulate air pollutants: Particulate air contaminants, also known as particulate matter (PM), are minute solid or fluid particles suspended in the environment. Particulate matter is divided up into multiple forms:

i. *Total suspended particulate matter (TSPM):* When a high-capacity bulk sample is performed on a filter substratum, the concentration of pollutants collected. It contains particles of various sizes.
ii. *PM10:* These are elements with a thickness of not more than 10 µm.
iii. *PM2.5:* These are elements with a thickness of not more than 2.5 µm.
iv. *PM1.0:* These are elements with a thickness of not more than 1 µm.

Granulated molecules have dimension of 10 µm to 2.5 µm, while small particulates have a dimension of less than 2.5 µm. Ultra-small particles with a dimension of less than 0.1 µm are often classified as fine particles (PM 0.1).

2.6. Common Air Pollutants

Sulphur oxides, carbon monoxide, nitrogen dioxide, ozone, total suspended particulate matter, and lead are six typical air contaminants, as per the EPA.

1) **Sulphur oxides:**
   Sulphur dioxide is a poisonous gas with a strong odour. Sulphur dioxide is one of the highly reactive gases of sulphur oxide (SO_x) group. SO_2 gas is formed when sulphur is reacted with oxygen at high temperature.

Sources:

- coal burning power plants and industries
- coal burning stove
- industrial boiler
- refineries
- heaters
- Vehicles
- Cement production units and copper smelting industries

Effects:

- React in atmosphere resulting in the formation of acid rain which deteriorate buildings and statues.
- Eye irritation
- Lung damage

- Circulatory collapse
- Adverse effect on aquatic life
- Highly corrosive
- Leaf injury and discoloration
- Addition of SO2 in aerosol produces classical or London smog

2) **Carbon Monoxide:**

Carbon monoxide is a toxic gas, when present at high concentration can cause death. It has no color and no odour, so cannot be detected by just smelling. It is the most abundant of the criteria pollutants.

Sources:

- Methane oxidation
- Fossil fuel burning
- Hydrocarbon oxidation
- Biomass burning

Effects:

- Carbon monoxide has an indirect radioactive forcing effect by elevating concentration of methane and tropospheric ozone.
- Carbon monoxide is a part in the series of reactions that forms photochemical smog.
- Leads to the formation of carboxy-haemoglobin when inhaled in high concentration.
- Headache, dizziness and chest pain.

3) **Nitrogen oxide:**

Nitrogen oxide refers to a binary compound of oxygen and nitrogen. The oxides of nitrogen are nitrate (NO_3), nitric oxide (NO), nitrous oxide (N_2O), nitrogen dioxide (NO_2), etc. Out of these oxides two namely NO, NO_2 are major air pollutant. These two are also responsible for the formation of smog and acid rain.

Sources:

- Vehicles

- Industrial boiler
- Power plants
- Domestic heating
- Coal used as a fuel in power plants

Effect:

- Formation of acid rain, destroying the forest, building and monuments
- Corrosion of Brass, Nickel, fading of textile dyes and cause material strength loss.
- Formation of ozone and other pollutants(smog)
- Lung damage
- Cause Pneumonia and bronchitis
- Strong contributor to eutrophication
- Cause chlorosis (deficiency of chlorophyll)

4) **Ozone:**

Ozone is gas which is blue in colour. It is a secondary air pollutant i.e.; it cannot directly emit from the sources. It can be generated by combining oxygen molecules and oxygen atoms. It is a powerful oxidizing agent which reacts with other chemical compounds to make toxic oxides.

Sources:

- Reaction of ozone precursors NO_x, CO and VOCs in the atmosphere assisted by the energy from sunlight.

Effects:

- Result in cataract, melanoma, damage to DNA & RNA & reduction in photosynthesis.
- Greenhouse gas
- Skin cancer
- Lung damage
- Eye irritation
- Respiration problem
- Cause cracking of rubber products

5) Particulate matter ($PM_{2.5}$ and PM_{10})

$PM_{2.5}$ - $PM_{2.5}$ is particulate matter whose aerodynamic diameter is not more than 2.5µm

PM_{10} - PM_{10} is particulate matter whose aerodynamic diameter is not more than 10µm.

Particulate matter has a great impact on earth. They influence the earth energy budget, cloud formation, cycles of life (nitrogen cycle, carbon cycle, hydrogen cycle). Particulate matter can be removed from the atmosphere by wet and dry methods. Particle of size less than 10 µm can be termed as RSPM (Respirable Suspended Particulate Matter).

Sources:

- Vehicle emissions
- Power plants
- Steel industry
- Soot and dust
- Wood used for domestic heating

Effects:

- Lung damage
- Reduce visibility
- Fade the colour of building and monuments
- Eye irritation

6) Lead:

Lead is an extremely toxic heavy metal that disturbs various physiological processes of an organism. Lead causes air pollution when present in fuel. Many countries use fuels with additives like tetraethyl lead. Lead can remain in the environment for long time in the form of dust.

Sources:

- Gasoline loaded with lead
- Paint
- Power plants

- Metal purification and extraction

Effects:

- Kidney and brain damage.
- Crop damage
- Smog
- Slow growth and learning disability, further leads to memory loss

2.7. Methods for measuring air pollutants

1) NO_x (Nitrogen Oxide)

- Bubbling air from a sodium hydroxide solution (NaOH) and sodium arsenite, identified as absorbing solution, gathers ambient nitrogen oxides.
- The concentration of Nitrogen oxide produced during the sampling is absorbing solution is determined by colorimetric analysis using the chemicals-
  - H_2O_2 (Hydrogen Peroxide)
  - Sulphanilamide
  - NEDA (N-1 naphthyl ethyldiamine dihydrochloride).
- Measuring the concentration of NO_x at the absorbance at 540nm with the help of Spectrophotometer.
- *Absorbing Solution*: Dissolve 4gm of sodium hydroxide in distilled water and add 1gm of sodium arsenite and diluted to 1000ml.
- *Standard used for Calibration Curve*: Sodium Nitrite Solution
- *Name of Method*: Jacob & Hoehhiser Method

2) SO_2 (Sulphur Dioxide)

- Ambient Sulphur oxides is absorbed from air in a solution of TCM (Potassium tetrachloromercurate) called absorbing solution.
- A dichlorosulphitomercurate complex forms, which is resistant to oxidation by air.
- Powerful oxidants, for instance ozone and nitrogen oxide, have no effect on the complex.

- Concentration of sulphur dioxide produced during the sampling in the complex (absorbing solution) is measured colorimatically using the chemicals-
    - Formaldehyde solution
    - Sulphamic acid
    - Pararosaaline solution
- Measuring the concentration of NO_x at the absorbance at 560nm with the help of spectrophotometer.
- *Absorbing Solution:* Dissolve $HgCl_2$ with KCl and EDTA in distilled water and dilute to 1000 ml to make the solution called TCM (Potassium tetrachloromercurate)
- *Standard used for Calibration Curve:* Sodium Thiosulphate Solution
- *Name of Method:* Improved west & Gaeke Method

3) $PM_{2.5}$

- Collected on the principle of the cascador impactor.
- The air sample is cascaded through a series of progressively finer nozzles.
- The air jet from the nozzle is impacted on a collection surface and analyzed gravimetriclly.
- *Instrument:* $PM_{2.5}$ sample collected over the filter papers with the help of Anderson sampler or fine particulate sampler.

4) PM_{10} or RSPM (Respirable Suspended Particulate Matter)

- Collected on the principle of the Cyclone Precipitator (Gravimetric).
- Air sample is passed through a cyclone which separate larger particle using centrifugal force and rest are collected on a sampling surface and weighed.
- *Instrument:* PM_{10} sample collected over the filter paper with the help of RDS (Respirable Dust Sampler).

5) Arsenic and Nickel

- Particulate matter sample collected over the filter paper is digested in nitric acid (HNO_3) called Acid Digestion.

- After digestion metals are analysed with the help of ICP-AAS (Inductively Coupled Plasma- Atomic Absorption Spectrophotometer).

2.8. Air Pollution and Meteorology

Air quality can vary from site to site even though emissions may remain relatively constant. The factor which determines this, is weather i.e., how strongly are the wind blowing and in which direction the wind is blowing, what is the temperature, how much sunlight is available? The parameters of the environment, or meteorology, decide air quality.

Meteorology: It is a technique through which we can observe the change in earth's atmosphere; variations in temperature, heating of earth surface and moisture patterns that produce different weather conditions. It is used to understand the phenomena such as hurricanes, thunderstorms, tornadoes and typhoons.

Scales of meteorology:

i. *Microscale* – It is the research of atmospheric phenomena on a scale of 1 km or less. Clouds, individual thunderstorms and local air turbulence caused by obstacles such as buildings and hills are modelled on this scale. Microscale meteorological events include gusts, dust devils, updraft and downdraft.

ii. *Mesoscale* – It's the analysis of atmospheric phenomena on a 1km to 1000km scale. Mesoscale timescales range from less than a day to weeks. Mesoscale phenomena are based on the principle of convection in which light warm air goes up and heavy cold air sinks down. It causes continuous circulation of air. The dispersion of air pollutants released near surface is also caused by this process. Typical events of this scale are thunderstorms, tornados, land breeze and sea breeze.

iii. *Synoptic scale* – It is the analysis of atmospheric phenomena on a scale of larger than 1000 km and time period of 10^5 sec (28 days). Extra tropical cyclones, hurricanes or typhoons are typical events included in

synoptic scale. The synoptic scale events are driven by the high- and low- pressure areas visible on the weather map.

iv. *Global scale* – Global scale phenomena are large- scale weather patterns that affect the large area of the globe. These includes tropic to poles transfer of heat and have time periods on the order of months or years. Very large scale phenomena such as Madden-Julian oscillation, El Nino-Southern Oscillation and Pacific decadal oscillation are representative of global scale meteorology.

2.9. Atmospheric Stability

Atmospheric stability is the measure of the capability of the atmosphere to be stable, unstable or neutral with different weather systems, place and time. The word "stable" means which is balanced and cannot change. "unstable" means that changes with time. For example, clouds change their shape with time and indicate unstable conditions. Atmospheric stability depends upon lapse rate, solar isolation, temperature gradient, cloud cover, wind speed and pressure gradient. It is divided into three categories: stable, unstable and neutral.

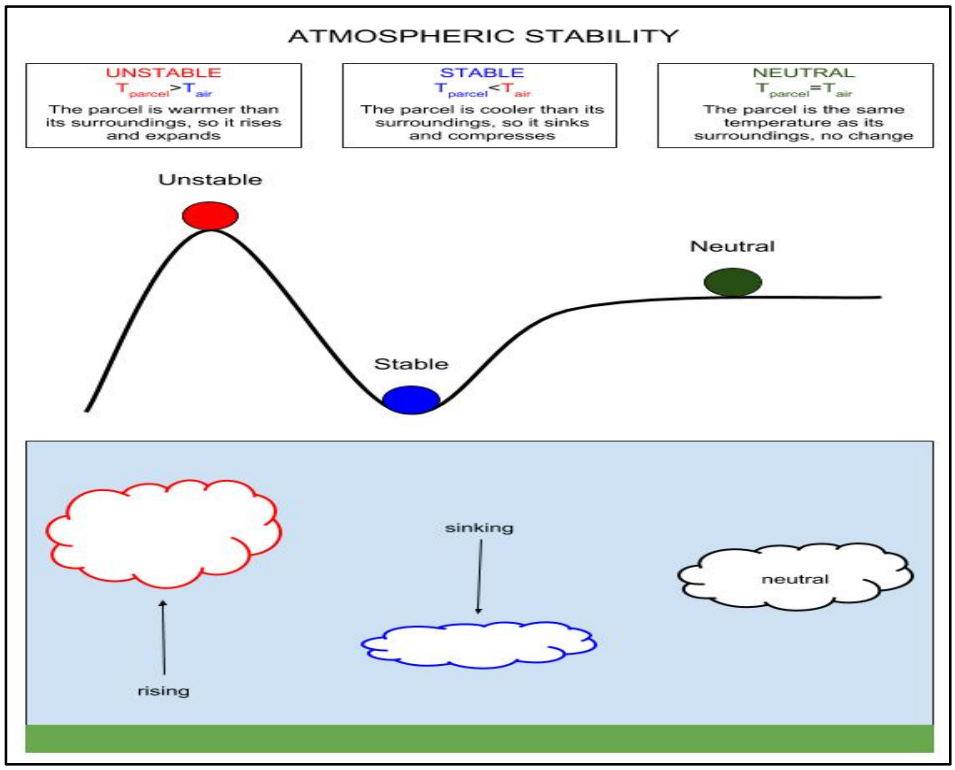

Figure 2: Stability and instability in relation to air and parcel temperature.

- ✓ In case of Unstable, the air parcel is warmer (less dense) than the surrounding environment, so it expands and rises upward in a vertical direction like a hot air balloon.
- ✓ In case of Stable, the air parcel is cooler than the surrounding environment, so it compresses and sinks downwards like a stone drop down in water.
- ✓ In case of Neutral, the air parcel is at the same temperature as its surrounding environment. No change takes place.

NOTE:

Lapse Rate: It is the decrease of temperature with height.

Lapse rate (Γ)= -dT/dz

where, dz = Change in altitude

dT = Change in temperature

Inversion: It is the increase in temperature with height.

Different Types of Processes:

1. Isothermal process: Process in which temperature remains constant ($\Delta T = 0$).
2. Adiabatic process: Process in which heat change remains constant ($\Delta Q = 0$).
3. Isobaric process: Process in which pressure remains constant ($\Delta P = 0$).
4. Isochoric process: Process in which volume remains constant ($\Delta V = 0$)

2.9.1 Atmospheric Stability & Lapse Rates

The atmosphere stability involves the comparison of rising air parcel temperature with the surrounding environment temperature at same altitude. It can be described with the help of environmental lapse rate. Generally, temperature decreases as we move upward with increase of height.

ELR (Environmental Lapse rate/Normal lapse rate): The amount by which the temperature of atmosphere decreases over each unit of vertical distance is called environmental lapse rate (ELR). It varies from place to place and time to time but average is about 6.5 $^{\circ}$C per kilometre.

DALR (Dry Adiabatic Lapse rate): The amount by which an individual air parcel cools for each unit of vertical distance that it rises depends mainly

whether it is saturated or not. If a parcel is not saturated, it will always cool by 9.8 ˚C per kilometre, this is called dry adiabatic lapse rate. The warm air parcel rises up and expands adiabatically leading to decrease in its temperature. Once the air parcel cools down it sinks down and compresses adiabatically thus warms up and the process repeats again.

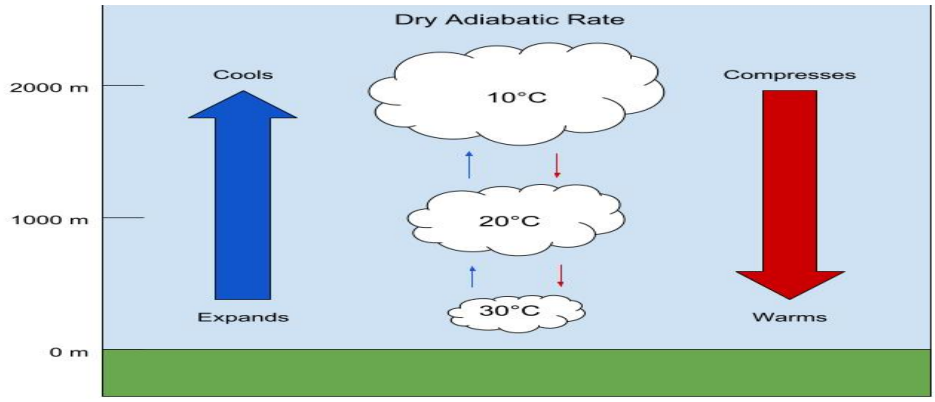

Fig.3 Dry adiabatic lapse rate condition

SALR (Saturated Adiabatic Lapse Rate): If a parcel is saturated, then it will cool down more slowly as it rises, because water vapour condenses in the parcel as it cools, which converts the latent heat into heat in the parcel, reducing adiabatic cooling. The rate at which saturated air parcel cools as it rises is called saturated adiabatic lapse rate. The average value of SALR is nearly about 4 ◦C per kilometre.

2.9.2. Different Conditions of Atmospheric Stability

A. Stable/Absolutely stable: It takes place in sub adiabatic condition when dry adiabatic lapse rate is more than the environmental lapse rate. Stable atmosphere restricts vertical air movement.

DALR > ELR

If the dry lapse rate is greater than saturated adiabatic lapse rate which is gain greater than environmental lapse rate, and it doesn't matter whether air is saturated or not, we say the air is absolutely stable.

DALR > SALR > ELR

B. Unstable/Absolutely unstable: It takes place in super adiabatic condition when Dry adiabatic lapse rate is lesser than the environmental lapse rate. It encourages vertical air movement.

$$ELR > DALR$$

If the environmental lapse rate is greater than the dry adiabatic lapse rate which in turn is greater than saturated adiabatic lapse rate, and it doesn't matter whether air is saturated or not, we say the air is absolutely unstable.

$$ELR > DALR > SALR$$

C. Neutral Stability: It is the condition of saturation when environmental lapse rate is equal to dry adiabatic lapse rate. This situation is quite common in windy, well mixed conditions in the lower troposphere. Air heated at the ground is rapidly mixed upwards by convection and turbulent winds, thus equalizing temperature.

$$ELR = DALR$$

D. Conditional Stability or unstability: It is the condition when environmental lapse rate lies in between the dry adiabatic lapse rate and wet adiabatic lapse rate. In this air parcel can be unstable or stable depending on the relative humidity of the parcel. If the air parcel is moist or saturated, the condition is unstable and if the parcel is dry, the condition is reverse or stable.

$$DALR > ELR > SALR$$

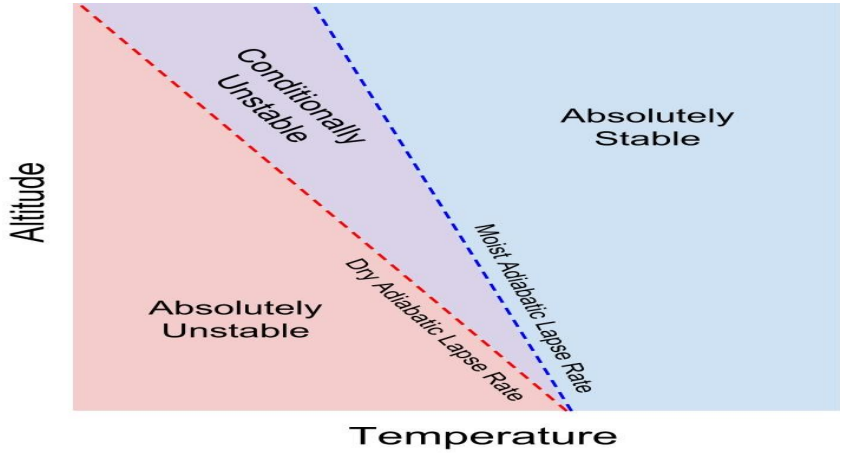

Fig.4 Diagram showing the different conditions of the atmosphere stability based on the dry and moist adiabatic lapse rates.

2.10. Plume

Plume is a path and extent of the atmosphere of the gaseous effluents released from a source called a stack (chimney).

Different types of Plume:

i. *Looping plume:* Looping plume is occurring in when ELR>ALR, rapid mixing of pollutant makes the atmosphere unstable. Looping plume looks like a wave. It is observed in the afternoon when the air parcel tends to mix rapidly in upward and downward direction. As a result high concentrations of pollutants may be observed near the surface of the ground.

ii. *Coning plume:* Under sub-adiabatic conditions (ELR < DALR), when there is limited vertical mixing and environment is slightly stable, the plume attains cone like structure and is called coning plume. It usually occurs when clouds block solar radiations during day time.

iii. *Fanning Plume:* Fanning plume is formed when extreme inversion condition occurs. Under this inversion condition, the environment is stable just above the stack. Due to the stable atmosphere above the stack plume does not move upward and there is only horizontal movement of the plume. It is observed in the early morning when the air parcel tends to remain at origin. It occurs when ELR < DALR and in less disturbed (less turbulence) condition.

iv. *Lofting plume:* Lofting plume also occurs in the inversion condition. But the atmosphere above the stack is unstable and below the stack is stable. Therefore, the upward movement of plumes is very rapid and pollutants mix well and cover long distances from their origin. This type of plume is ideal for the dispersion of pollutants. In this, mixing in upward direction is uninhibited but downward motion is restricted by the inversion layer. That's why pollutants cannot settle down towards the ground.

v. *Fumigation:* It occurs in the negative lapse rate condition. Atmosphere above the stack is stable and below the stack is unstable. Due to unstable atmosphere below the stack pollutants cannot escape and

occur near the ground level. Therefore, fumigation plume is bad for the dispersion of pollutants and affects human health. It is the reverse of the Lofting plume. It forms when the stack is under an inversion layer. Emission moves downward more easily than upward. The resulting fumigation plume can leave a greatly elevated downward condition.

vi. *Trapping plume:* In trapping plume pollutants get trapped between two inversion layers. Pollutants cannot move upward or downward. These types of plume are not ideal for the dispersion of air pollutants. It is limited to a certain height.

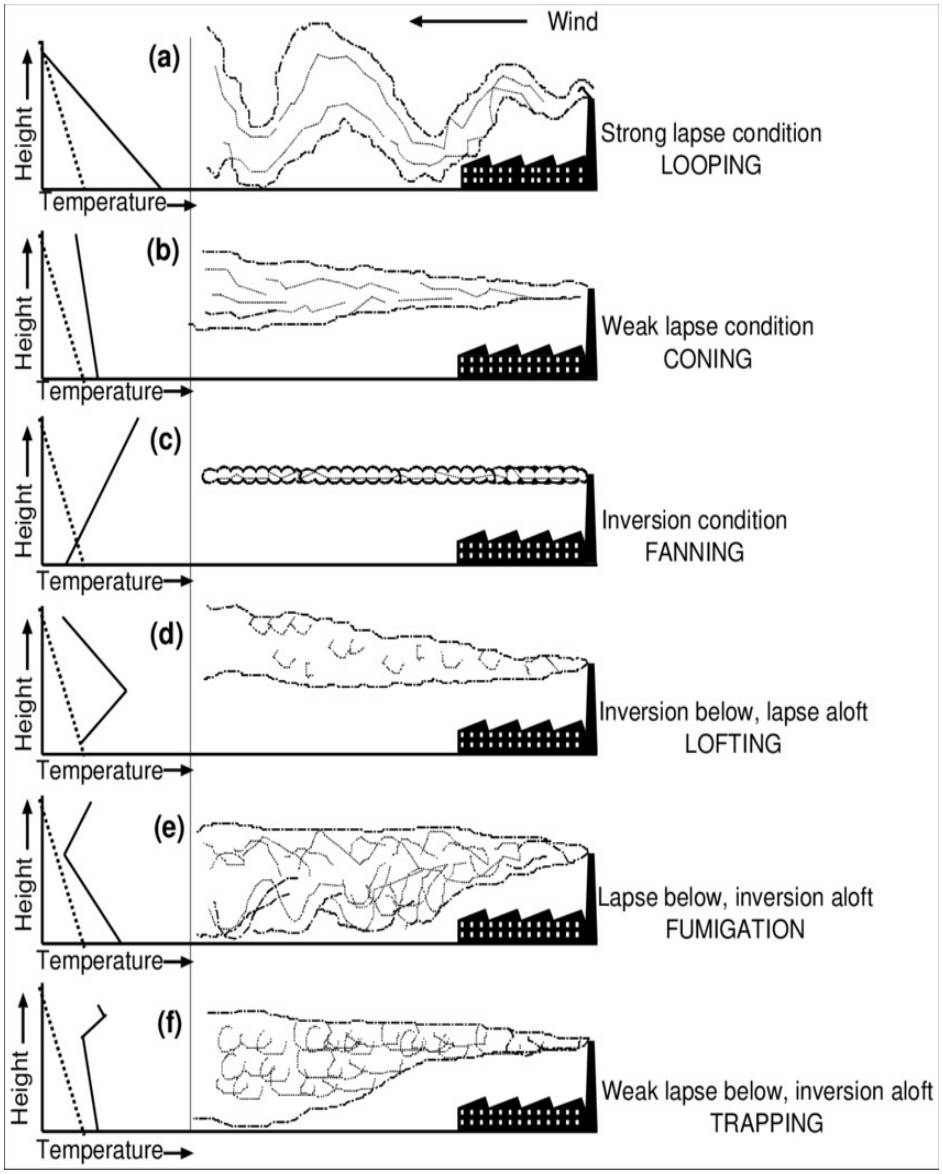

Fig.5 Different Types of Plume

2.11. Summary

In this unit we have studied that:

- The ever growing human population and subsequently increasing demands for food, energy and other goods are leading to higher consumption of natural resources which are not only resulting in their depletion but the by-products of their usage are causing the contamination of environment.
- Air pollution is the increased concentration of a contaminant in the air that causes an undesirable change in the quality of air thus affecting the wellbeing of humans and other organism. Among the 30 most polluted cities in the world 22 are in India.
- Pollution in the closed space of a room is called as indoor air pollution. The indoor air pollutants are CO, VOCs, indoor particulates, tobacco smoke and others. Population groups which stay indoors most of the time like children, women and elderly are most affected by this. Lack of proper ventilation amplifies the effect of indoor air pollution.
- Outdoor air pollution on the other hand affects the general human population and ecology as well the materials. Outdoor air pollutants are SO_x, NO_x, particulate matter ($PM_{2.5}$, PM_{10}), ozone and heavy metals.
- Air pollutants can be classified on different basis: natural or anthropogenic on the basis of source, primary or secondary on the basis of origin, organic or inorganic on the basis of chemical composition and gaseous or particulate on the basis of state of matter.
- Monitoring of air pollutants is done using a number of methods depending upon the nature of pollutant. NO_x and SO_x are measured colorimetrically using an absorbing solution and complexing reagents. While particulate matter is monitored by gravimetric analysis. Heavy metals and many other pollutants are measured using AAS.

- Meteorological processes affect the dispersion of air pollutants. The convective currents which cause the circulation of air in the troposphere also help in dispersion of pollutant preventing them from concentrating in a localized area.
- Stable atmosphere or occurrence of inversion layer in the troposphere can lead to concentration of pollutants near ground surface. Different patterns of smoke plumes released from a stack are also caused by these phenomena.

Terminal Questions

1. Define air pollution. What are the different kinds of pollution? Explain
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   ……
   ……
   ……
2. Explain different scales of meteorology.
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   ……
   ……
   ……
3. Define two anthropogenic sources of air pollution.
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   ……
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   ……
4. Name the method used for measuring Sulphur Dioxide (SO_2).

……
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……
……

ANSWERS

1. Hint: Pg. 2, 5
2. Hint: Pg. 11, 12
3. Hint: Pg. 4, 5
4. West & Gaeke Method

Unit 3: Air Pollution: Effects and Control

Unit Structure

3.0. Learning objectives

This chapter explains:

- ✓ Air pollution
- ✓ Air pollutants (Primary and Secondary Pollutants)
- ✓ Causes and Effects of air pollution
- ✓ Effective techniques to control or reduce air pollution
- ✓ Standards of ambient air quality

3.1. Introduction

Air pollution, the greatest environmental evil has become a major public concern. Change in the concentration of any substance that

exists in the air to an extent that it causes harm to living and nonliving things is called air pollution. Air has both life supporting and life damaging properties. Clean and dry air consists of mainly Nitrogen (78.084%), Oxygen (20.946%), Argon (0.9340%), Carbon dioxide (0.0415%) and the rest includes other noble gases, oxides of nitrogen and other gases. A chemical species which deteriorates the quality of air is called contaminant. Globally the major concern is about air pollution and its influence on every organism, plants, animals and even property at all levels (local, regional and global). India is one of the most polluted counties in the world. According to a study by WHO in 2016, approximately 140 million people respire air polluted beyond safe limits. Air pollution is caused majorly due to industries (51%), followed by vehicles (27%), slash burning (17%) and fireworks (5%). After China and U.S, India is considered as largest emitter of greenhouse gases and one of the riskiest places to breathe. In 2020, 22 cities are from India out of total 30 most polluted cities in the world.

The air pollution effects:

- Human health,
- Animals,
- Plants, and
- Other archeological sites and buildings.

3.2. Air Pollutants

Air pollutants are the solid, liquid and gases substance that deteriorate or lowers the quality of air and their high concentration cause threat to human health, plants and animals. Air pollutants are of two types:

I. **Primary Air Pollutants**:It includes the pollutants which are directly from the source and cause harm to human, plants and animals in original form.

For example, Hydrocarbons, Carbon monoxide, NO_X (Mixture of NO + NO_2), SO_2, Particulate matter ($PM_{2.5}$ and PM_{10}), Hg vapours, Ammonia (NH_3), Lead (Pb).

II. **Secondary Air Pollutants**: Secondary pollutants formed when primary pollutants react with each other in presence of sunlight or oxygen.

For example, Tropospheric ozone (Ground- level ozone), Acid rain, Peroxyacetyl nitrates (PAN), H_2SO_4, SO_3, NO_3^-, HNO_3, H_2O_2, SO_4^{2-}, Photochemical smog etc.

Criteria pollutants

It includes the pollutants whose concentrations beyond a permissible limit are harmful for human health. Criteria pollutants are established by Environmental protection Agency under Clean Air Act and set national ambient air quality standard for them. Criteria pollutants play an important role in atmospheric chemistry.

There are 6 criteria pollutants:

- Carbon monoxide (CO)
- Sulphur dioxide (SO_2)
- NO_2
- Particulate matter ($PM_{2.5}$ and PM_{10})
- Lead (Pb)
- Tropospheric Ozone (Secondary ozone or Bad ozone or Ground-level ozone)
- Ammonia (NH_3)

3.3. Sources of Air Pollution

Causes of Air Pollution can be natural or man-made (anthropogenic).

Natural Source:These are the sources which occur naturally in the environment. It includes volcanic activities, increasing temperature, forest fires, wind and air currents, radioactive decay, thunderbolts, wind erosion, biological material like pollen, spores etc.

Anthropogenic or artificial Source: Sources which occur due to the influence of human activities. It includes deforestation, combustion of fossil fuels, smoking, mining, biomass burning, organic solvents like paints, smelting, agriculture (pesticides/insecticides), landfill disposal, transportation and other industrial processes etc.

Air pollution sources can be categorized into:

Point sources – such as power plants, oil refineries, factories

Line sources – such as railway lines, road ways, navigation routes, airports

Area sources – such as cities, agricultural fields, forest fires

3.4. Effect of Air Pollution

3.4.1. Effect on Human Health

Air pollution has become health hazard for humans. It mainly affects the respiratory system. Various diseases are caused due to exposure of polluted air are bronchitis, silicosis, asbestosis, asthma, cough, emphysema, lung cancer, laryngospasm, fatigue, headache, anxiety, irritation in eyes, nervous system damage and cardiovascular damage.

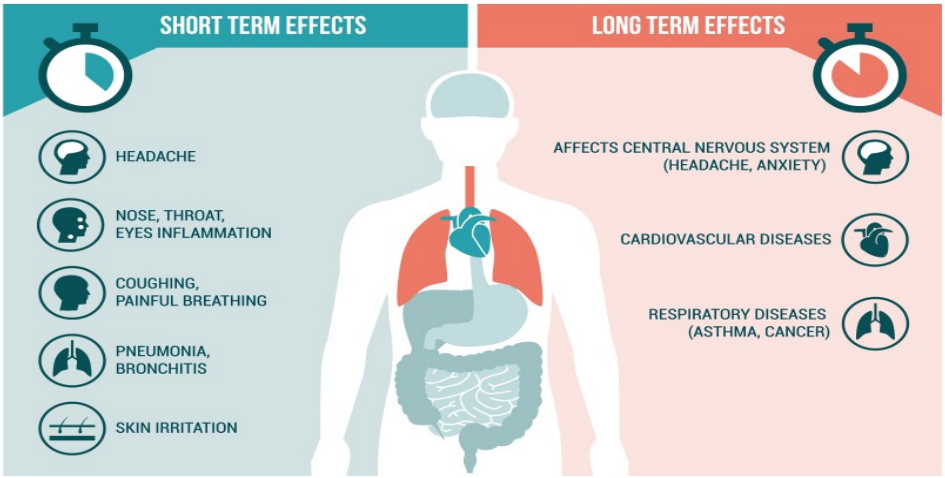

Fig 1: Air pollution effects on Humans

- Sulphur dioxide (SO_2) is most serious and widespread air pollutant. It acts as an allergic agent and damage lungs. It contributes to the formation of H_2SO_4 which is the main component of acid rain.

$$SO_2 + H_2O \rightarrow H_2SO_3$$

$$H_2SO_3 + H_2O \rightarrow H_2SO_4$$

- Carbon monoxide (CO) influences binding capacity of oxygen to blood. CO reacts with haemoglobin present in blood and combines to form carboxy haemoglobin (COHb). Carbon monoxide has a 200 times more affinity for haemoglobin than oxygen. So it can combine with haemoglobin even at low partial pressure

$$O_2Hb + CO \rightarrow COHb + O_2$$

Where, O_2Hb = oxy-haemoglobin

- Mercury is produced from burning of fossil fuels in power plants and leads to damage of brain, nerve and kidney.
- Nitric oxide act as respiratory irritant and leads to acute bleeding of lungs (pulmonary hemorrhage).
- Nickel is emitted from burning of fuel oils, mining and refining and incineration of municipal waste and results in respiratory damage, cardiovascular and kidney diseases and even cancer.
- Lead acts as toxicant which causes brain damage. Its effects extend to mental disability, comma, muscle spasm and leads to death in severe conditions.
- Particulates of cadmium cause, kidney failure, cardiovascular diseases, and liver damage.
    - Hydrogen sulphide is also toxic. Effects range from headache and eye irritation to unconsciousness and death.
    - Radioactive particles cause genetic and semantic effects like cancer, mutation and radiation sickness.
    - Smog is also result of air pollution and has killer effect. E.g., London smog nearly killed 1200 people in 1952.

Table 1: Effect of air pollutants on health by varying concentration

Air Pollutants	Concentration (ppm)	Health Disorders
1. CO	10	Impairment of judgement & vision
	100	Headache, dizziness
	250	Loss of consciousness
	> 700	Death (60% CoHb)
2. NO_2	50 – 100	Inflammation of lung tissue
	150 – 200	Bronchiolitis fibrosa
	> 500	Death
3. SO_2	> 5	Trachial irritation & cough
	5 – 10	Bronchial spasms
	> 200	Death
4. O_3 & PAN	> 5	Irritation of eyes & respiratory tract
	> 50	Death due to pulmonary edoma
5. Particulates	> 100	Respiratory hazard, Cardiovascular change

Due to air contamination, 7 million people died per year (WHO, 2012). According to Lancet report, 2019, 1.7 million peoples of India died due

to air pollution. WHO (World Health Organization) set Threshold Limit Values (TLV) to the maximum concentration of pollutants to which healthy person are permitted to be exposed for a particular period of time. According to WHO 2019, 91% of the world's population is living in areas beyond a limit set by WHO guidelines. 9 out of 10 people respire contaminated air globally. 16kg of air/day is taken by an average man by breathing 22,000 times in a day. The impact of air pollution on human health is more during winter, when pollution level reaches its climax due to low mixing. Different factors which affect the human health are:

- Nature and source of contaminant
- Pollutant concentration
- Exposure time
- Age group of affected person
- Health state of receiver

Table 2: Health effects and Air Quality Guidelines for air pollutants

Pollutant	WHO guidelines		Effects
	Annual mean ($\mu g/m^3$ of air)	98 percentile ($\mu g/m^3$ of air)[a]	
Sulphur dioxide	40 – 60	100 – 150	Exacerbations of respiratory illness from short-term exposures. Increased prevalence of respiratory symptoms, including chronic bronchitis from long-term exposures
Suspended particulate matter			
Black smoke	40 – 60	100 – 150	Same as for SO_2
Total suspended particulates	60 – 90	150 – 230	Combined exposure to SO_2 and SPM[b] may have pulmonary effects
Lead	0.5 – 1	—	Blood enzyme changes. Anemia. Hyperactivity and neurobehavioural effects
Nitrogen dioxide			
1 hour	400	—	Effects on lung function in asthmatics from
24 hours	—	150	short-term exposures
Carbon monoxide			
15 minutes	100,000	—	Reduced oxygen-carrying capacity of blood

3.4.2. Effect on Animals

Animals are adversely affected by air pollution. It affects their lungs, cardiovascular system and nervous system. Moreover pollutants may settle on the vegetation which might be consumed by animals. Metals accumulate in animal bodies through food chain and cause danger to animal health like

heavy metal poisoning cause diarrhea, anemia and stiffness. Lead poisoning leads to inflammation of mucous membrane (bronchitis) and appetite loss.

- Aquatic life in streams and lakes are destroyed due to the formation of acid rain or acid deposition.
- Ozone cause skin cancer and destroys lung tissues in animals.
- Presence of toxic elements in air enforces animals to migrate from one habitat to another.

3.4.3. Effects on Plants

- Air pollution harms flora and foliage globally. If the absorption level of pollutants is in excess then the cells die and ultimately tissues collapse. Lesions, drying of leaves are common symptoms. It interferes with photosynthesis and respiration of plants. It results even into death.
- Air pollutants enter into plants directly by gaseous diffusion or from the contaminated soils. Gaseous pollutants enter directly by stomata of plants and solid particulates are absorbed on surface. Penetration of pollutants into plants is mainly through the leaves.

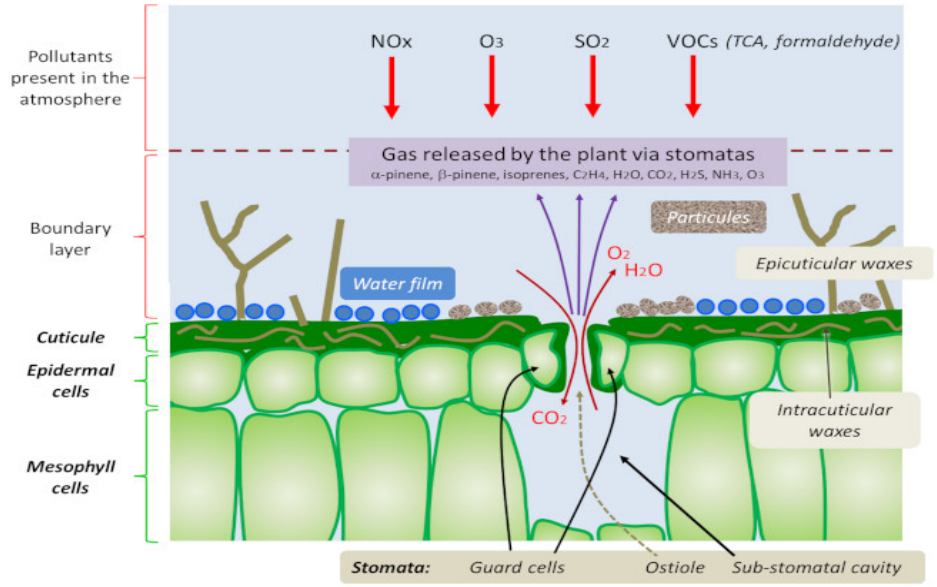

Fig 2: Absorption of pollutants through leaves.

- Air pollution affects the energy exchange as the sun's energy falling on leaf surface is reduced due to dust layer. Air pollutants can be stored in plants and introduced into food chains, which further affect other animals who feed on them.
- Plant growth and metabolism is reduced due to pesticides used in agriculture activities. Chlorophyll destruction and photosynthesis interruption takes place when exposed to high amount of pollutant.

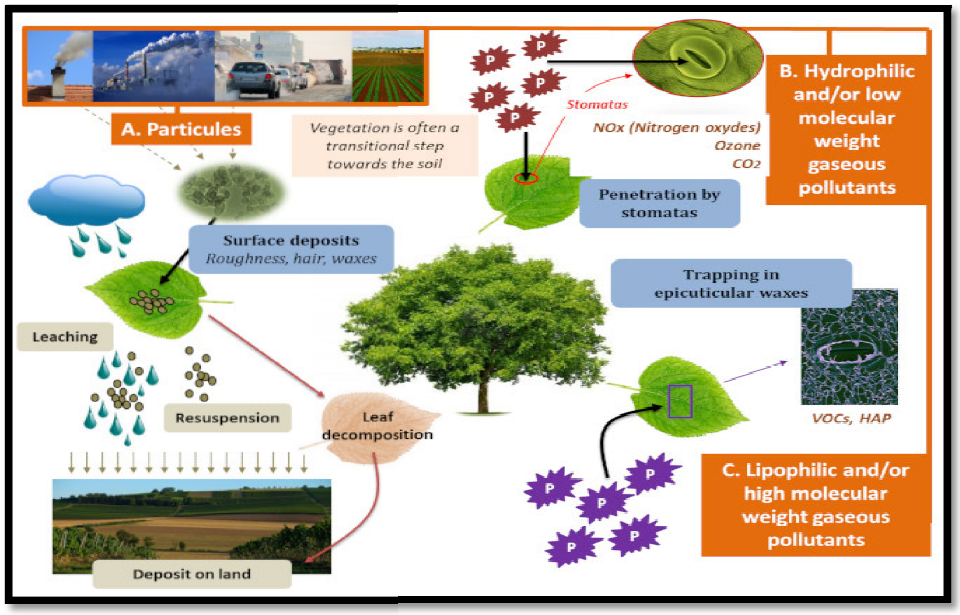

Fig 3: Behavior of different air pollutant towards vegetation

- SO_2 extract chlorophyll from leaves and cause chlorosis (i.e. yellowing of leaves due to chlorophyll loss). It can also effect stomatal opening resulting in excess loss of water.
- NO_2 cause abscission (premature leaf fall) and suppress growth of plants.
- Ozone causes necrosis (condition in which cells and tissues of organism die) which makes the plant more susceptible to pests and diseases.
- Peroxyacylnitrate (PAN) harms leaf vegetables by curling and bleaching of leaves.

Table 3: Air pollution effect on Plants

Pollutants	Phytotoxic concentration (ppm/h)	Symptoms
(A) MAJOR POLLUTANTS:		
(a) Sulphur dioxide	0.1 – 0.5	Interveinal bleaching and marginal bleaching, chlorosis, discolouration (red/brown)
(b) Oxides of nitrogen	0.21 – 100	Chlorosis and marginal bleaching
(c) Ozone	0.04 – 0.70	Bronzing, Chlorosis, coloured fleck
(d) Fluorides	0.001 – 0.10	Chlorosis, particularly along the leaf margin, marginal necrosis from leaf tips to leaf bass
(B) MINOR POLLUTANTS:		
(a) Ammonia	0.001 – 0.10	Leaves turn dull green and the brown or black glating or silvering on the underside of leaves.
(b) Ethylene & propylene	0.0005 – 10	Leaf curling.
(c) Particulates (with toxic metals)	100 – 500	Chlorosis followed by reddening & yellowing, necrosis, bleaching of leaf margin.

3.4.4. Effects on archeological sites and buildings

Air pollution also damages buildings and structures. Iron, aluminum alloy, copper, steel and other metals are also deteriorated due to rusting in presence of polluted air. Structures are mainly affected due to

- ✓ Rusting
- ✓ Chemical attack
- ✓ Abrasion
- ✓ Material elimination and deposition

Damages caused by air pollution to building are

- ➢ Construction material gets damaged due to presence of sulphur dioxide, aerosols and acid rain.
- ➢ SO_2, particulates and hydrogen sulphide leads to dissolution of paints.
- ➢ Leads to oxidation and rusting of metals.
- ➢ Ozone, SO_2 and NO_2 discolors, deteriorates and lowers the mechanical strength of fabrics.

Table 4: Air pollution damage to buildings and material

Material	Damage	Responsible Air pollutants
Metals	Tarnishing, corrosion, structural weakening	Acidic gases*, moisture, salt
Masonry	Surface erosion, soiling	Acidic gases, moisture, particulate matter
Ceramic	Surface erosion, encrusting	Acidic gases, especially hydrogen fluoride
Paints	Surface erosion, discolouration	Acidic gases, H_2S, ozone, particulate matter, moisture
Paper	Embrittlement, discolouration	Acidic gases, moisture
Textiles	Reduced strength, soiling	Acidic gases, moisture
Textile dyes	Fading	Ozone and oxides of nitrogen in sunlight
Leather	Weakening	Oxides of sulphur
Rubber	Cracking	Ozone
Photographic film	Blemishes	Oxides of sulphur, moisture

*Unless otherwise noted, "acidic gases" refer to oxides of nitrogen and sulphur that react with moist air to form the strong acids H_2SO_4 (sulphuric acid) and HNO_3 (nitric acid).

- Buildings get damaged due to long exposure to sulphates. H_2SO_4 causes damage to marble buildings by formation of $CaSO_4$ which is more soluble and leaves a pitted appearance on marbles.

$$CaCO_3 \text{ (insoluble)} + H_2SO_4 \rightarrow CaSO_4 \text{ (soluble)} + H_2O + CO_2$$

For example, Taj Mahal is turning yellow due to air pollution. In 1972, sulfur dioxide and soot particles released from oil refinery at Mathura lead to acid rain which caused yellowing of Taj Mahal. When the acids fall on the marble they react and cause "Marble Cancer".

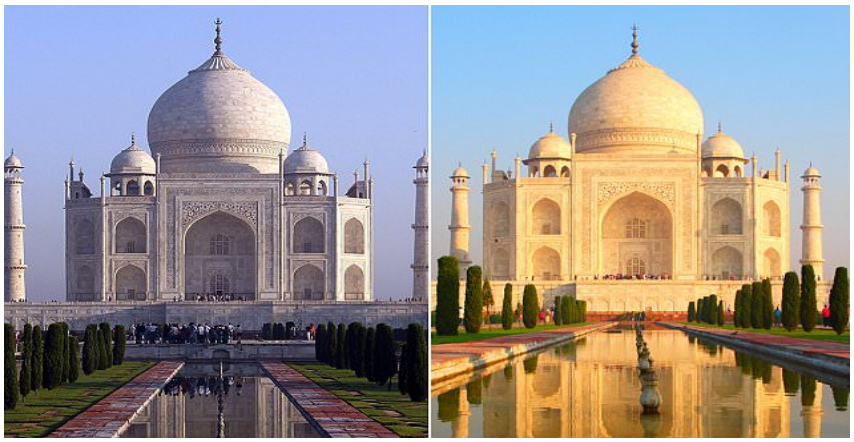

Fig 4. Taj Mahal is turning yellow due to air pollution

3.5. Air Pollution Control Techniques

The different ways used to control air pollution are:

1. Direct capture method
2. Techniques for pollutant removal
3. Diffusion
4. Plants
5. Sectioning method (zoning)

3.5.1. Direct Capture Method

Industries play a major role in causing air pollution. The pollutants release in air can be minimized or prevented directly by controlling them at their source. It includes elimination, prevention and reduction of pollutants at its sources. Different methods used for source control are:

3.5.1.1. Raw material substitution

It includes the replacement of existing raw material which causes air pollution by the other materials that produce less waste and are non toxic in nature. For example,

- High sulphur fuels are replaced by low sulphur fuels to reduce the formation of sulphur dioxide.
- Coal and biomass fuel are substituted by more pure fuels like LPG (Liquid petroleum gas) and LNG (Liquefied natural gas).

3.5.1.2. Modification in technology or process

It includes the change in technologies or process to reduce pollution emission by using alternate technologies like use of counter- current washing and reducing the cleaning frequency. For example,

- Coal is washed before crushing or grinding to reduce fly-ash emission.
- The emission of fly ash has reduced by adjustment of air intake at power plants.

3.5.1.3. Equipment Modification

It includes changes in design and characteristics of equipments to reduce pollution which improves instrument maintainability, functioning, reliability and safety concern. For example the design of storage tank used in petroleum refineries are changed to floating roof covers to reduce loss of hydrocarbon vapours. It can also do by pressurizing the tanks.

3.5.1.4. Equipment Care and Maintenance

Emissions of pollutants are reduced by proper care and maintenance of equipments. It includes corrective repair work and routine checkups to reduce the risk associated with the instrument and to provide safe and healthy working environment.

3.5.2. Techniques for Pollutant Removal

It includes a series of pollution control instruments to prevent gaseous and particle pollutants. The factors considered during installing of a suitable and appropriate device are toxicity, particle size, collection efficiency, cost, concentration, pressure drop and corrosivity.

3.5.2.1. Equipment to control Particulate pollutants

The two major categories to classify pollution control equipment's are:

(i) Equipment to control particulate matter.

(ii) Equipment to control gaseous pollutants.

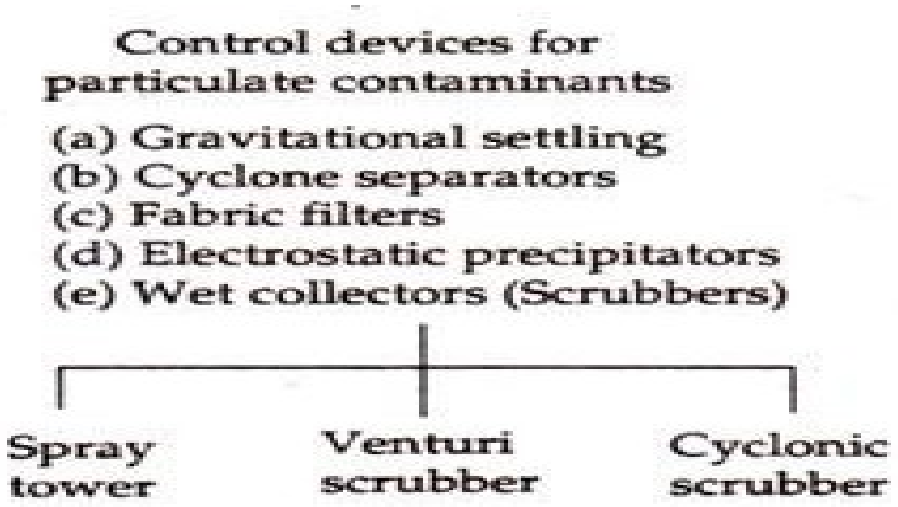

Fig 5 Classification of control equipments for particulate contaminants

3.5.2.2. Gravitational Settling Chamber

It is the simplest method used to remove particles of more than 50μm size present in polluted gas. It works on the principal of gravity. This is the simplest device in which exhaust gas velocity is slow down sufficiently to allow large particles to settle down by gravity. Collection efficiency can be increased by installing a series of settling chamber. It has large rectangular chambers consisting of different horizontal trays. Polluted gas enters from inlet present at one side. The polluted gas stream is allowed to move at low

velocity so that the particles get enough time to settle down on the bottom of chamber consisting of dust hopper. Then, particulate matters are removed directly from dust hopper. The multiple horizontal plates used in settling chamber increase the collection efficiency of particles by increasing their settling path.

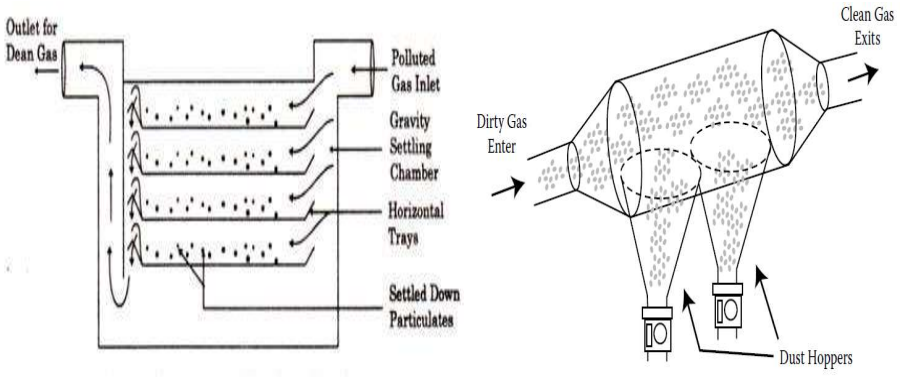

Fig 6: Gravitational settling chamber

3.5.2.3. Cyclonic Precipitator or Centrifugal separator (Reverse flow Cyclone)

Cyclone separator works on the principle of centrifugal force to remove particulate matter from the contaminated gas. It is cylindrical in shape with conical base. The dirty gas enters tangentially from the inlet present at the top of instrument. After entering of gas inside the cylindrical body, the gas spins due to centrifugal force. The gas in the separator forces the particles against the outer wall of separator by centrifugal force. The particles then drop out at bottom into the hopper due to gravity and removed ultimately. The cleaner gas exits the collector from top. It is inexpensive and maintenance free but not much efficient. Efficiency is 60-90% for PM_{10} and 20-70% for $PM_{2.5}$.

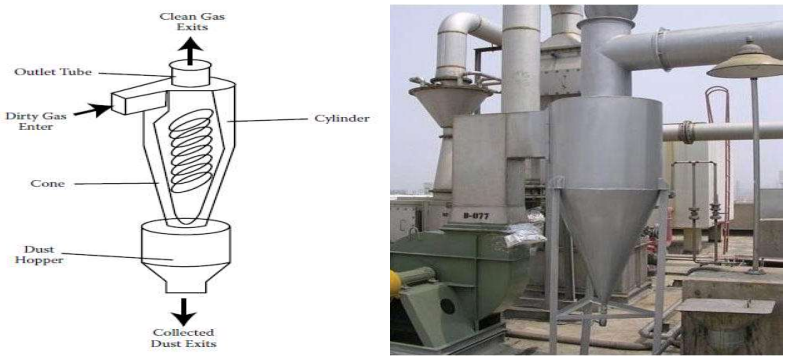

Fig 7: Cyclone Separator

3.5.2.4. Bag houses (Fabric Filters)

It is the most efficient technique for the removal of particulate matter from polluted air. It consists of large amount of fabric filter bags. It contains a tubular or cylindrical bag which is closed at the top and opens at the bottom which leads to hopper for the collection of pollutants removed from the fabric. When the polluted air is transferred through the bags the particulates get filtered out. The particulate matter gets accumulated inside the bags which are then settled down at the bottom in hopper (conical base) and removed. The clean air exists out from the outlet.

It is 100% efficient for removing sub-micron(less than 1μm) particles. It is expensive and has high maintenance. Maintenance cost of fabric filter is very high. They cannot work in moist condition and at high temperature. If the gas contains any corrosive material, the fabric filter bags get damaged. The filter bags should be cleaned occasionally with the help of mechanical shaker to increase its life.

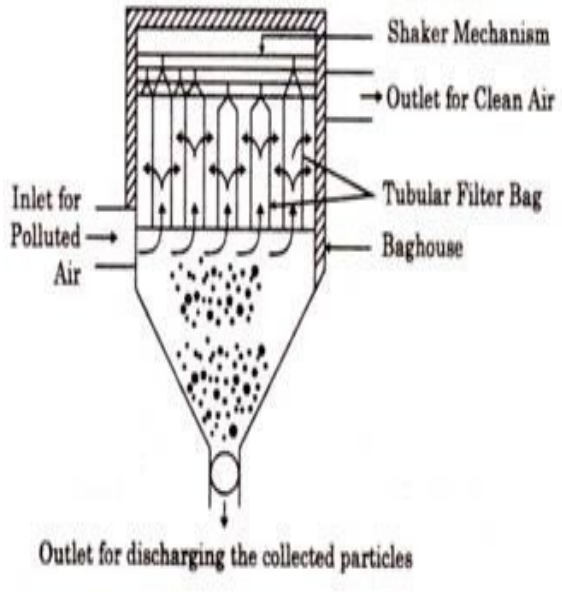

Fig 8: Bag House

3.5.2.5. Electrostatic Precipitators

It is most efficient device used for removal of ultrafine particles. It consists of:

i. Grounded collector plates (positive charged).
ii. Insulator to hang the electrode wire from the top of precipitator.
iii. High voltage negatively charged discharged electrode wire
iv. To keep the wire in position a weight is hanged at bottom of it.

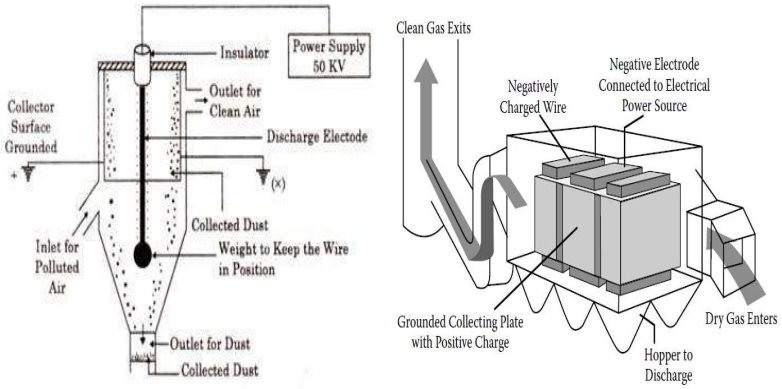

Fig 9: Electrostatic Precipitator

The high voltage negatively charged discharge electrode wires are placed parallel between the grounded collector plates. Electrode wires are maintained at 20 to 80 KV. It produces a corona discharge due to intense electric field around the wire that produces electrons. These electrons get attached to dust particles and give them negative charge. The collection plates are grounded and attract the negatively charged dust particles toward itself by influence of electric field. Then, the particulate matter is removed from collection plates by flushing with any liquid or by gravitational forces.

Their efficiency is very high approx. 98% even for sub – micron < 1µm particles. They are costly and has huge space requirement. It requires small power for its working.

3.5.2.6. Scrubbers

These are used to remove particulate matter and gas present in polluted air. It is a device which utilizes water to remove particulate pollutants from polluted air. It is divided into three types. Their collection efficiency depends on particle concentration, liquid gas ratio and flow velocity.

Different types of scrubber are:

- Spray Tower
- Venturi Scrubber
- Centrifugal wet Scrubber

(i) Spray Tower:

It is a simplest type of wet scrubber, in which the polluted gases rises from the bottom while water is sprayed down from a number of nozzles present at top. The particles more than 10µm are washed out from the polluted gas by the

water slowly. The particulate pollutant combined with water droplets settle down in the hopper of spray tower due to the influence of gravitational force and are removed. It is low energy scrubber.It has more than 90 percent of removal efficiency.

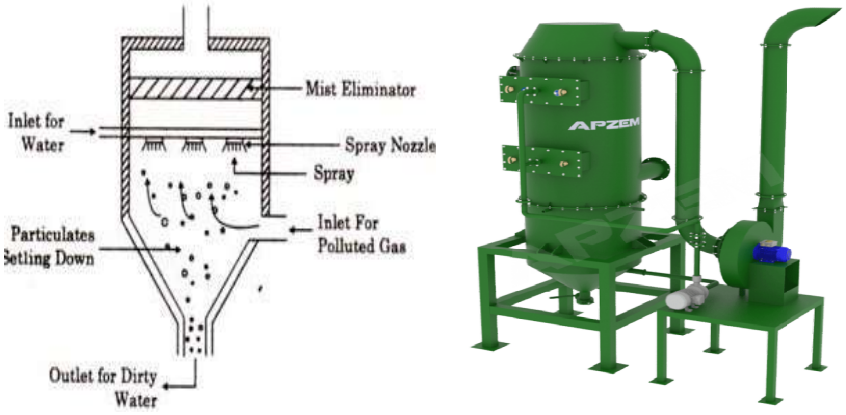

Fig 10: Spray Tower

(ii) Venturi Scrubber

It is high energy wet scrubber used for removal of submicron particulates having 0.5 to 5µm in size from polluted air. It consists of a Venturi shaped throat section. The polluted gas enters the venturi throat vertically down from the inlet at a particular velocity. The velocity should be in range of 60 to 180m/sec. As the gas encounters the throat, the scrubbing liquid (water) is injected or sprayed upward in the polluted gas. The water gets atomized into small droplets due to turbulence and high velocity of gas. Therefore, the interaction between water droplets and polluted gas increases.

Now, the particles get attached or captured by water droplets which are then removed from the air with the help of other separation device like cyclone separator connected to it. It is easy to install and have low maintenance cost.

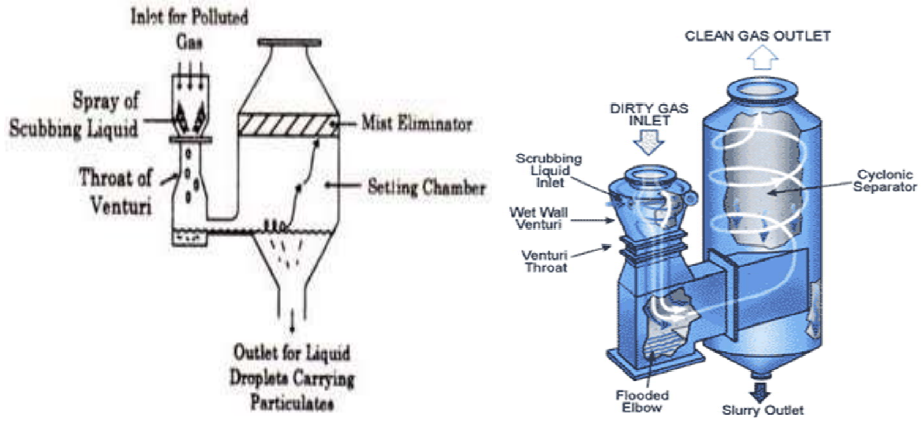

Fig 11: Venturi Scrubber connected to Cyclone separator

(iii) Centrifugal wet Scrubber:

It is similar to cyclonic precipitator except presence of high pressure nozzles in it. As the polluted gas enters the chamber, the nozzles spray water at high pressure. The water comes in contact with particles and forces them towards the wall of scrubber by centrifugal force. Then the particles are dragged down into the bottom due to gravity and clean air exits from the top of scrubber. It has high removal efficiency of approx. 99 percent.

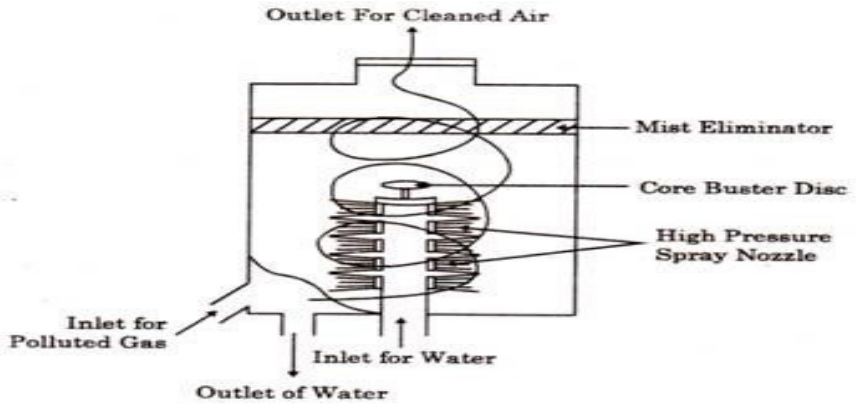

Fig 12: Cyclone Scrubber

3.5.3. Equipments to control gaseous pollutants

3.5.3.1 Absorption

It is a technique in which polluted air is transferred through a medium containing a suitable absorbent matrix (contacting liquid), which adsorbs gaseous pollutant that exists in air. Contact liquid like water act as a solvent and capture pollutants present in air by chemically reacting with them. The pollutant reactswith the contacting liquid and gets trapped in it. The devices have removal efficiencies of 90-95 percent. Absorption process can be carried out in different devices like packed scrubbers, or towers etc. For example, sulphur dioxide (SO2) from the polluted air is removed with the help of an absorption process known as **FGD (Flue gas desulphurization)**. In which the SO2 present in flue gas released from the power plants react with the contacting liquid (either slurry of solid material or liquid) used and trap them.

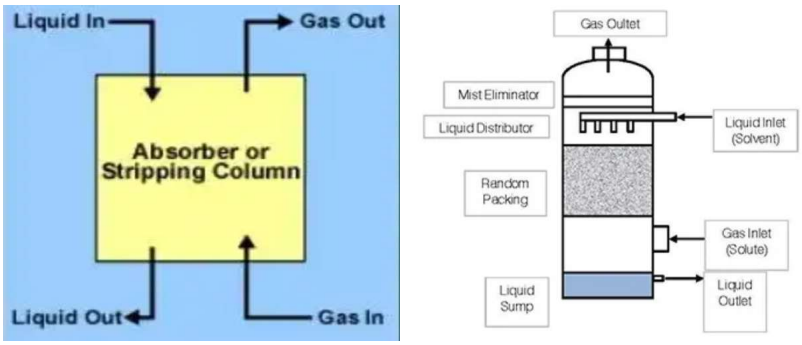

Fig 13: Process of absorption

The efficiency of this process depends on following factors

a) Relationship between gas – liquid surface area
b) Absorber concentration
c) Reaction velocity
d) Contact time

Different absorbers used to remove gaseous contaminants are:

Oxides of Nitrogen – water, aqueous nitric acid

SO_2 – Ammonium sulphate, sodium sulphite, calcium sulphate, calcium sulphite, alkaline water

HF – water, sodium hydroxide

H_2S – NaOH & phenol mix, sodium alamine & potassium dimethyl glycin, ethanolamines etc.

3.5.3.2 Adsorption

It is the process in which the polluted gas is transferred through an adsorption matrix. The pollutants present in the air are adsorbed at the surface of the adsorbent and clean air passes through it to out. The pollutants removed are called adsorbate and the process done by the matrix on which pollutant deposited is called adsorbent.

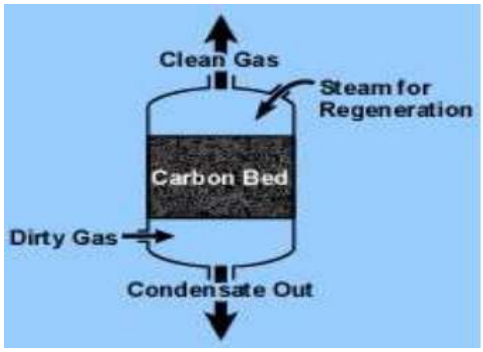

Fig 14: Process of adsorption

It is commonly used in industries to remove organic and inorganic compounds. The adsorbents used in industries are carbon bed, zeolite, silica gel, activated bauxite, alumina etc.

Factors important in the removal of gaseous pollutants are

a) Adsorbent physical and chemical nature

b) Adsorbent surface area
c) Temperature and pressure
d) Nature and concentration of the gas
e) Gas recovery

Different types of adsorbent commonly used in purifying air are

SO_2 – limestone

H_2S – iron oxide

Oxides of nitrogen – silica gel

Organic solvent vapours – activated carbon

HF – lump limestone

It can be further divided into two types.

Fixed bed adsorber (FBA): It consist of fixed adsorbent bed used for the removal of gaseous pollutants.

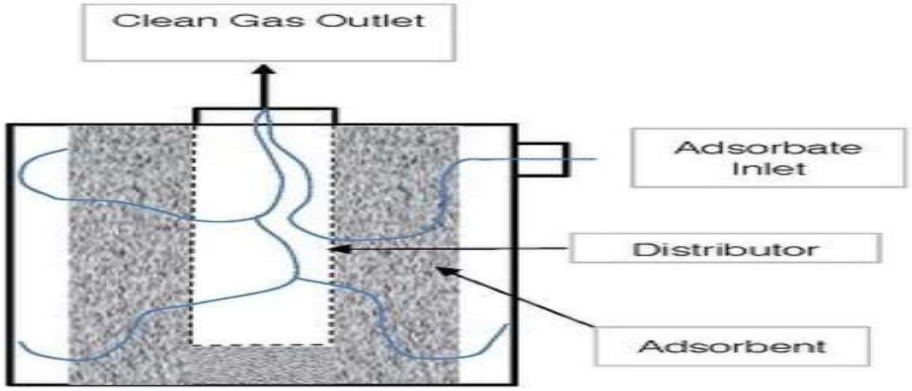

Fig 15: Fixed bed adsorber

In this technique, the polluted air enters into the chamber through inlet and passes through the fixed adsorbent matrix. The pollutants are adsorbed on the surface of adsorbent. Clean air enters into distributor and then exits out from outlet.

Moving bed adsorber (MBA): It is continuous adsorption model with a cylindrical bed. The cylindrical bed moves around its axis slowly. It consists of

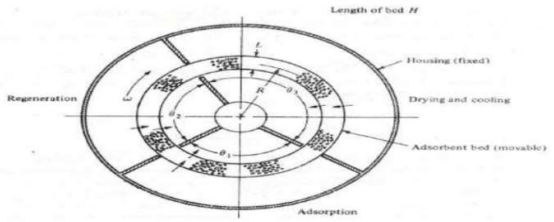

Fig 16: Moving bed adsorber

adsorption bed which continuously circulates in different phases or sections. It involves adsorption of pollutants, regeneration, cooling and drying of gas. In this process less adsorbent is used as it is regenerated continuously. It is more complex and expensive method in comparison to fixed bed adsorber.

3.5.3.3. Combustion

It is the process of oxidation in presence of heat. It mainly converts the gaseous pollutants into water and carbon dioxide. High temperature, catalyst for reaction, proper mixing or turbulence are different factors responsible to completely oxide the pollutants present in air. It is mainly used to remove organic gaseous pollutants emitted from paint factories, paper mill and refineries. It can be divided into three different methods used to remove gaseous pollutants, which are:

a. Direct Combustor or flaring
b. Thermal oxidation
c. Catalytic oxidation

Direct Combustor: It is a thermo-chemical technique. In this, the biomass or combustible waste are burned is presence of excess air with the help of burner.

Thermal Incinerator: It is a device in which oxidation takes place at high temperature. It involves the oxidation of pollutants by raising the temperature above its ignition point. Polluted gas enters into the combustion chamber and passes over the burner flame. Oxidation of gas takes place and clean air passes out. It has 99% efficiency to destroy pollutants.

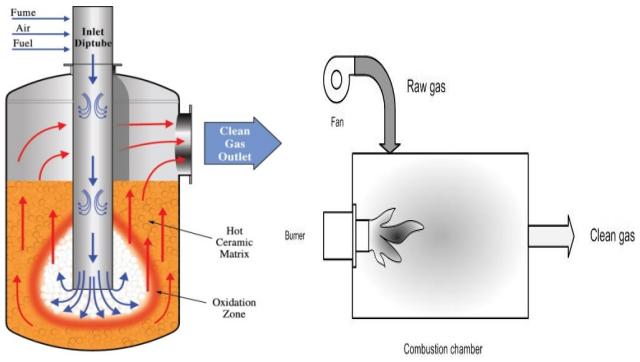

Fig 17: Thermal Incinerator

Catalytic incinerator: It is similar to thermal incineration in working except presence of catalyst bed in it. In this technique, air passes from the burner flame and is transferred to the catalyst bed. Pollutants are oxidized with the help of catalysts. Catalyst increases the efficiency of instrument as it decreases the time of reaction. It works on low temperature. Efficiency is more than 95 percent.

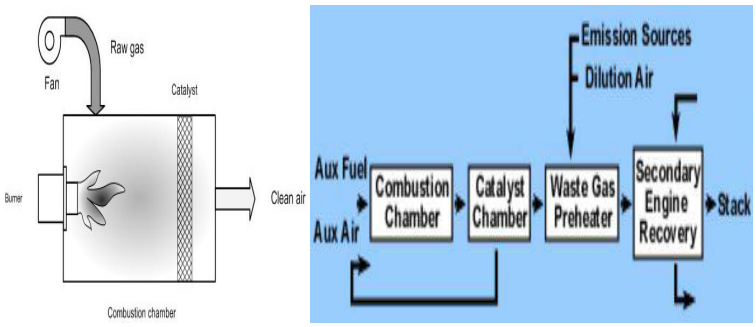

Fig 18: Catalytic incinerator

3.5.3.4 Condensation

It is a process of conversion of gas into liquid by increasing its pressure and lowering its temperature. They are pre-treatment devices. It has removal efficiency ranges from 50 percent to more than 95 percent. It is of two types: direct contact and indirect surface condenser.

Contact condenser (direct condenser): In this, the gases come into contact with cold liquid. It is operated by mixing of contaminated gas with the cooling medium. They are usually simple and low cost devices.

Surface condenser (indirect condenser): It is widely used condenser. In this, the gases are circulated outside the tubes with cooling medium which act as physical barrier. In this, contaminated gas is kept separate from the coolant medium.

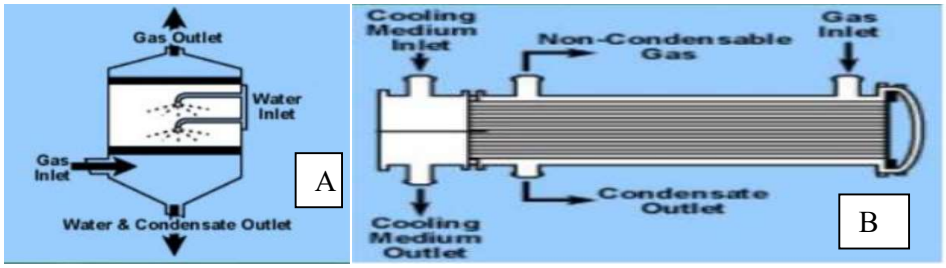

Fig 19: (a) Contact Condenser and (b) Surface Condenser

3.5.4. Diffusion

Diffusion of contaminants present in polluted air is also another approach for pollution removal. If the pollutants are emitted in small quantity then the pollution is not identified as it easily dispersed into the atmosphere. But if pollutants are present in excess or crosses the limit of environment to absorb, adsorb and remove pollutants, pollution occurs which adversely affects the environment.

Dispersion of pollutants in air depends on direction, velocity and temperature of wind. It can be controlled by proper construction of stacks above the inversion to reduce ground level pollution.

3.5.5. Plants

Plants used carbon dioxide and released oxygen which also plays an important role in removal of pollutants. Plants purify the air. Plants are known to have ability to absorb and metabolize gaseous pollutants.Plants remove pollutants from air through stomata uptake, absorption, and adsorption to plant surfaces. Plant leaf act as biofilters & are able to capture pollutants.

The rate of reducing pollutants by plants is influenced by plant species, light intensity and pollutant concentration. There are different plants used to remove pollutants *Epipremnum aureum, Pyrus, Ficus variegate, Shingonium podophyllum, Brassica juncea,Thlaspi carulescens, Helianthus annus, Phascolus vulgaris* etc. the process of removal of pollution with the help of plants is called Phytoremediation.

3.5.6. Zoning

Zoning is one of the pollution regulation methods of government based on human health, comfort, welfare and convenience. It is divided into agricultural, commercial, residential and industrial zones. WHO sets a particular emission criteria or limit for emission of pollutants in different zones.

It is method of controlling air pollution adopted in cities at stage of planning. Zoning separates the residential area from industrial area. Industries must be far from residential area due to air pollution in concern of health and should not be located close to each other. New industries are actually situated away from larger cities due to concern of increase in urban density. Populated cities like Delhi and Bangalore are not permitted for industries.

3.6. Standards of Ambient Air Quality

NAAQ (National Ambient Air Quality Standards) are the standards or limits for ambient air quality set by the CPCB (Central pollution Control Board) which is used across the nation. It consists of guidelines and allowable level of harmful air pollutants. These standards for air quality are set by CPCB on 18, November 2009 under the Air (Prevention and control of Air Pollution) Act (1981).

Table 5: National Ambient Air Quality Standards (2009)

Pollutants	Time weighted average	Industrial, residential, rural and other areas	Ecologically sensitive area (notified by central government)	Methods of Measurement
Sulphur dioxide (SO_2), µg/m^3	Annual*	50	20	Improved West and Gaeke Method
	24 hours**	80	80	Ultraviolet Fluorescence
Nitrogen dioxide (NO_2), µg/m^3	Annual*	40	30	Jacob & Hochheiser modified (NaOH-$NaAsO_2$) method
	24 hours**	80	80	Gas Phase Chemiluminescence
Particulate matter (size less than 10 µm) or PM_{10}, µg/m^3	Annual*	60	60	Gravimetric
	24 hours**	100	100	TEOM
				Beta attenuation
Particulate matter (size less than 2.5 µm) or $PM_{2.5}$, µg/m^3	Annual*	40	40	Gravimetric
	24 hours**	60	60	TEOM
				Beta attenuation
Ozone (O^3) µg/m^3	8 hours*	100	100	UV Photometric
	1 hour**	180	180	Chemiluminescence
				Chemical Method
Lead (Pb) µg/m^3	Annual*	0.5	0.5	AAS/ICP Method after sampling on EPM 2000 or equivalent filter paper
	24 hours**	1	1	ED-XRF using Teflon filter
Carbon Monoxide (CO) µg/m^3	8 hours**	2	2	Non dispersive Infrared (NDIR) Spectroscopy
	1 hour**	4	4	
Ammonia (NH3), µg/m^3	Annual*	100	100	Chemiluminescence
	24 hours**	400	400	Indophenol blue method
Benzene (C_6H_6), µg/m^3	Annual*	5	5	Gas chromatography (GC) based continuous analyser
				Adsorption and desorption followed by GC analysis
Benzo(a) Pyrene (BaP) particulate phase only, ng/m^3	Annual*	1	1	Solvent extraction followed by HPLC/GC analysis
Arsenic (As), ng/m^3	Annual*	6	6	AAS/ICP Method after sampling on EPM 2000 or equivalent paper
Nickel (Ni), ng/m^3	Annual*	20	20	AAS/ICP Method after sampling on EPM 2000 or equivalent paper

Air Quality Index (AQI) is an index to measure the quality of air on daily basis. It reports the effect of air pollution on human health over a short period of time. AQI is introduced by Environment Minister Shri Prakash Jawedkar on 17th September 2014 under Swacch Bharat Abhiyaan in New Delhi. The objective of AQI is to aware peoples about the health impacts caused by air

pollution and change in air quality. AQI mainly composed of 8 pollutants (PM_{10}, $PM_{2.5}$, NO_2, SO_2, CO, O_3, NH_3 and Pb). It is divided into 6 categories on the basis of their exposure time, concentration, and health effects and rates them as good, bad, satisfactory etc.

Table 6: Air Quality Index rating scale

Air Quality Index Levels of Health Concern	Numerical Value	Meaning
Good	0 to 50	Air quality is considered satisfactory, and air pollution poses little or no risk.
Moderate	51 to 100	Air quality is acceptable; however, for some pollutants there may be a moderate health concern for a very small number of people who are unusually sensitive to air pollution.
Unhealthy for Sensitive Groups	101 to 150	Members of sensitive groups may experience health effects. The general public is not likely to be affected.
Unhealthy	151 to 200	Everyone may begin to experience health effects; members of sensitive groups may experience more serious health effects.
Very Unhealthy	201 to 300	Health alert: everyone may experience more serious health effects.
Hazardous	301 to 500	Health warnings of emergency conditions. The entire population is more likely to be affected.

3.7. Summary

- In this unit we read the fundamental concepts associated with air pollution.
- Now, we know that air pollution is the undesirable change in the quality of air which causes ill effects on human health, animal life and plants as well as buildings and monuments. It is caused by increase in the concentration of a gas or particulate matter in the air beyond a particular limit.

- Air pollutants are classified into primary or secondary pollutants depending upon their origination. The pollutants emitted directly from a source are called primary sources and those which are generated by the reaction of primary pollutants in the air are called secondary pollutants.

- Pollutants directly affect humans and animals by causing respiratory, cardiovascular and neurological illness or by causing acid rains or smogs. Besides humans and animals, air pollution affects plants, reducing their photosynthetic efficiency, and also damages buildings and articles, corroding and discoloring them.

- Different control measures are employed to combat the menace of air pollution. Use of alternate raw materials and fuels are the first step in controlling air pollution. Maintenance of vehicles and industrial machinery is also helpful. Replacement of old and obsolete vehicles/machines with new and efficient ones is yet another major contributor in controlling pollutant emissions. Beyond source control removal of pollutants from effluent gas is employed using techniques and devices.

- National ambient air quality standards (NAAQS) are limits set by Central pollution control board (CPCB) on the allowable concentration of criteria pollutants in ambient air. The effects of air pollutants on human health are quantified using air quality index (AQI) rating scale. The higher the index more polluted is the air.

TERMINAL QUESTIONS

1. What is Air pollution?
   .....
   .....
2. Explain effects of air pollution on human health?
   .....
   .....
3. How plants and animals are affected by air pollution?
   .....
   .....
4. Explain effect of air pollution on buildings with the help of example?
   .....
   .....
5. Name different techniques use to control Particulate Matter?
   .....
   .....

6. What are the different methods used to control gaseous pollutants?

   ……

   ……

7. What is the composition of clean air?

   ……

   ……

8. Which of the following country is the largest emitter of Greenhouse gas?

   a. China b) Japan c) India d) US

9. Explain the effect of Carbon monoxideon human body?

……

……

10. Cyclonic precipitator works on:

    i. Principal of Centripetal force
    ii. Principal of Centrifugal force
    iii. Principal of Gravity
    iv. Principal of Frictional force

11. Define adsorbate and adsorbent?

    a. ……

       ……

12. What are the different absorbers used to remove gaseous contaminants?

    ……

    ……

13. How plants plays role in the removal of air pollution?

    ……

    ……

14. What is AQI and its objective?

    ……

    ……

15. What are the Criteria pollutants?……

    ……

    ……

ANSWERS

1. Air pollution is defined as change in the concentration of any substance exists in air to that extent which cause harm to living and non – living things.
2. Refer Page no. 3, 4, & 5.
3. Refer Page no. 6& 7.
4. Refer Page no. 8 & 9.
5. Different techniques used to control Particulate Matter are Gravitational Settling Chamber, Cyclonic separator, Electrostatic precipitator, Fabric filters, Scrubber.
6. Different methods used to control gaseous pollutants are Absorption, Adsorption, Combustion and Condensation.
7. Clean and dry air consists mainly of Nitrogen (78.09%), Oxygen (20.94), Carbon dioxide (0.03%), Helium (0.005%), Oxides of nitrogen (0.001%), Sulphur dioxide (0.0002%), Carbon monoxide (0.1%).
8. a) China
9. Carbon monoxide is a harmful gas when breathed. As it replaces oxygen present in the blood and influences binding capacity of oxygen. CO reacts with haemoglobin present in blood and combines to form carboxy haemoglobin (COHb). Carbon monoxide has a 200 times more affinity for haemoglobin than oxygen. So it can combine with haemoglobin even at low partial pressure causing you to lose consciousness and suffocate.

$O_2Hb + CO \rightarrow COHb + O_2$

10. a) Principal of Centrifugal force
11. The substance (pollutant) removed are called absorbate. The matrix on which pollutant deposit to done the adsorption process is called absorbent. For example, Carbon bed, Silica gel etc.
12. Different absorbent used to remove gaseous contaminants are Calcium Sulphite, Aluminium Sulphite, Sodium Hydroxide, glycin, Water, Aq. Nitric Acid, Sodium Sulphite etc.
13. Refer Page no. 20.
14. Refer Page no. 22.
15. Refer Page no. 2 & 3.

Unit 4: Noise Pollution: Causes, Consequences and control measures

Unit Structure

4.0. Learning objectives

After reading this chapter, you will be ready to:

- ✓ Detailed understanding of noise and its characteristics.
- ✓ Knowledge of Indian standards for noise.
- ✓ Familiarity with noise measure and instrument used.
- ✓ Having the ability to calculate noise
- ✓ Identify control measures

4.1. Introduction

As we all know that the pollution of air & water has been increasing day by day. Likewise, noise pollution is also increasing due to urbanization, increase in number of vehicles, modern lifestyle etc. Noise has been shown to reduce productivity, harm health, and increase accident rates, to name a few effects. Noise may damage hearing instantly at high levels, and gradual loss of hearing might be occurred at lower levels.

This chapter detailed about the sources, characteristics, and effects of noise, delineates its measurement and analysis methods, and lists some control measures that helps to reduce the problem.

4.2. Noise

Noise, am unwanted sound becomes a part of our day to day life due to advancement in industrialization. The progression of the machines in factories, steam engines, and petrol engines in the 19th century resulted in increase in noise level. The further increase in the levels of noise was accelerated with evolution of high-tech industries, vehicular traffic and construction site machineries in the 20th century. It has been acknowledged as the matter of concern for both human and environment. Noise is produced by human activities, especially urbanization and the expansion of transportation and industry. While pollution has a greater impact on the urban population, small towns/villages along side roads or near factories are also affected.

Figure 1: Noise

Source: http:// iconscout.com/icon/noise-1659489

Sound is the form of energy that consists of wave motion and travels through the medium i.e. solid, liquid and gas for its propagation while noise is the sound that causes exasperation in the hearing of a normal human being. Noise is measured by two important ways i.e. sound pressure and sound intensity. The sound intensity is measured in decibels (dB). Noise is one of the most serious issues, despite the fact that sound is essential for communication. Sound is the term used to describe intentionally induced auditory signals such as speech and music. The word "noise" is used to describe any unwelcome sound.

The term ‘noise’ is derived from the Latin word “nausea” that means ‘unwanted sound’ or ‘sound that is loud, noisy or unpredicted’ (figure 1).

4.3. Characteristics of Noise

For all practical purposes, noise may be defined as unwanted sound; therefore, sound characteristics are considered for better understanding of the noise that deteriorates our environment.

Sound is a form of energy which is produced from a vibrating body. These are the vibrations that cause pressure variation in the medium in which they travel. The interference brought in the medium due to pressure variation generates sound which is heard by our ears. Therefore, the sound is the any change in the pressure of the travelled medium.

There are two important characteristics of sound or noise - **frequency** and **loudness**.

Frequency – A sound wave comprised of the variation in the pressure or oscillation of a medium. The ambient pressure changes periodically as sound passes through air. The number of oscillation is called as the frequency of sound and also defined as the number of pressure variations per second and is measured in Hertz (Hz) i.e. cycles per second.

Loudness - The loudness of a sound or noise is another characteristic. A noisy noise has a greater pressure variation, while a weak noise has a smaller variation. The sound loudness depends on the intensity of the sound waves and intensity refers to the energy in the sound waves.

4.4. Propagation of Sound

Sound is produced by vibrating objects. A medium is the matter or material by which sound is transmitted. It may take the form of a solid, a liquid, or a gas. From the point of generation to the listener, sound travels through a medium. When an entity vibrates, it causes the medium's particles to vibrate as well. The particles do not make it all the way to the ear from the vibrating object. The equilibrium position of a medium particle in contact with a vibrating object is first displaced. It then applies a force to the particle next to it. As a consequence, the neighboring particle is shifted from its resting spot. The first particle returns to its original location after displacing the neighboring

particles. This method continues until the sound reaches the end of the medium in the ear.

The most popular medium for sound transmission is air. When an object vibrates, the front air particles of it compresses and in closet with each other forming a high-pressure zone. This area is referred to as a compression zone (C). When the **compression** begins to shift away from the vibrating object, it begins to vibrate less. When a vibrating object travels backwards, and produces a low-pressure area known as **rarefaction** (R). compression and rarefaction of sound was shown in figure 2.

Figure 2: Showing Compression & Rarefaction of sound (source-http://lossenderosstudio.com/glossary.php?index=r)

The sinusoidal pattern is generated by the simplest sound wave from a pure tone, and it is used to determine sound properties such as amplitude, frequency, and wavelength (shown in figure 3). These characteristics describe sound vibrations.

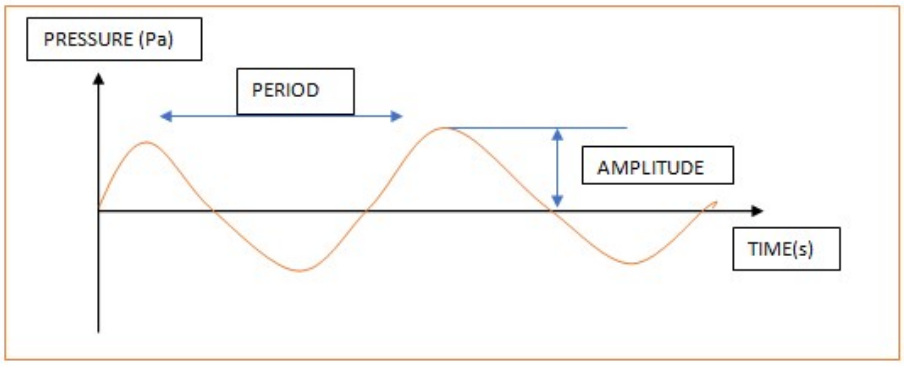

Figure 3: Simple wave motion

Amplitude-The amplitude of a sound wave is a measurement of the height of the wave and also determined its relative loudness. The maximum displacement of the vibrating object from its mean location can be described

as the loudness of a sound wave. It is the difference between the wave's crest or trough and its mean location. The highest part of the sound wave referred to as crest and the lowest part of it is called as trough.

Frequency-Frequency is the number of cycles repeated in a given amount of time. Cycle/sec or Hz is the unit of measurement (1 Hz= 1 Cycle/sec). Pressure waves with frequencies ranging from around 20 hertz (Hz) to 20,000 Hz make up audible sound. A **pure tone** is a sound that consists primarily of a single-frequency sinusoidal pressure wave. Infrasound has a frequency below the audible range i.e. 20 Hz, while ultrasound is a sound wave having frequency beyond the audible range i.e. 20,000 Hz.

Wavelength-The wavelength of a sound is the measurement of the distance between two adjacent equal parts of a wave. If a pure-tone pressure wave can be detected at a given moment, the wavelength could be directly defined as the duration of one cycle of the wave in propagation. Thus,

$$\lambda = \frac{c}{f}$$

Where, λ - wavelength (m),

c - propagation speed (m/s) and

f - frequency (Hz).

The sound wavelength affects the efficacy of noise filters and sound-absorbing materials.

4.5. Factors Affecting Sound Propagation

Propagation of a sound is complicated in an urban setting because it is obstructed by trees, houses, roads or ground surfaces, boundary walls, building facades and other objects, resulting in many reflections of the sound. The sound is affected by the atmospheric and surface constituents due to whom it is absorbed (by atmosphere and plants), reflected and transmitted (buildings or other structures).

Sound pressure and sound energy is directly affected and lost, respectively in its propagation due to the presence of such elements in the mixed urban climate. Atmospheric properties such as pressure, temperature, wind speed, ground surface, relative humidity, topography, trees, and other natural and artificial obstructions are important to note in the study of sound propagation.

These are also known as attenuation factors because they reduce the strength of sound.

4.6. Noise Measurement Units

As mentioned earlier, the two main parameters of noise measurements are - sound pressure and sound intensity. The decibel (dB) is a common scientific acoustic unit. It is defined as the ratio, expressed as a logarithmic scale relative to a reference sound pressure level, rather than an absolute physical unit like volt, metre, and so on.

The threshold of hearing is described as sound that can be perceived for the first time at a sound pressure of 2×10^{-5} N/m^2 or a sound strength of 10^{-12} W/m^2.

Noise metres are manufactured to track noise from low to high frequencies, which is typical of human hearing capability. These metres use the decibel scale to calculate noise levels in general. Peak noise levels, length of noise exposure, and noise efficiency, all of which are characteristics of a specific noise situation, have been taken into account by refined noise metres.

4.6.1. Sound Level Meter

A sound-level metre (figure 4), a hand-held instrument that provides either a linear evaluation of the time-varying pressure in decibels or a spectral breakdown of the signal, is widely used to measure noise levels. So, it is very important for us to understand this device carefully for measuring sound. It consists of following parts;

i. **Microphone** - A microphone is a device that allows you to speak through a microphone. The microphone detects changes in sound intensity and transforms them to an analogue electrical signal.

ii. **Preamplifier** -The preamplifier is used for impedance matching and can also supply the microphone with a DC polarization voltage.

iii. **Frequency Weighting Network** - This stage includes a network structure (generally A, C, and linear) for modifying the measurement instrument's frequency response characteristics. Depending on the form

of measurement, the required frequency weighting characteristic must be chosen.

iv. **Range Control Amplifier** - The range of signal levels for which most sound level metre detectors accurately work is small. The signal voltage is adjusted to levels that are within this range using this amplifier.

v. **Detector** - This factor is used to describe the amplitude of the incoming signal. Detectors come in a variety of shapes and sizes. RMS (root mean square), peak, and integrating are some of them.

vi. **Display** - The display is used to show the signal's amplitude after it has been detected. SLM displays are usually scaled in decibels based on the international norm of $2*10^{-5}$ Pa.

vii. **Outputs** - Signal outputs are often provided by sound level meter in order to obtain advanced interpretation and graphical hard copy.

Figure 4: Sound Level Meter (source-https://commons.wikimedia.org/wiki/File:Son%C3%B3metre_avan%C3%A7at_Classe_1_i_redu%C3%AFdes_mides.jpg)

The Sound Level Meter is made up of three globally recognized weighing networks. Weighing networks are electronic filter circuits built into the metre to reduce the frequency of a specific frequency. They allow the sound level metre to respond differently to some frequencies than others, similar to how human ears do. There are three weighing scales available;

i. **A weighing scale:** A-Weighting is the most common weighting used in noise calculation. It basically cuts the lower and higher frequencies

which an average person cannot detect, much like the human ear. A-weighted measurements are expressed in decibels (**dBA**) or decibels **dB** (**A).**

ii. **B weighing scale:** B weighting is similar to A weighting, but with less attenuation. For relatively high sound pressure levels, B weighting was an effort to approximate human understanding of loudness. It has become obsolete and is no longer in use.

iii. **C weighing scale:** The human ear's response varies depending on the volume of sound. The ear's answer is flatter at higher speeds, such as 100 dB and above. It is often used in peak measurements, as well as in some entertainment noise measurements at which bass noise transmission can be a issue. **dBC** or **Db (C)** are the abbreviations for C-weighted measurements (C).

iv. **Z weighing scale:** A flat frequency response of 10Hz to 20 kHz 1.5dB is achieved with Z-weighting. The older "Linear" or "Unweighted" responses were obsolete because they could not specify the frequency range at which the metre would be linear. **dBZ** or **Db (Z)** are the abbreviations for Z-weighted measurements (Z).

4.7. Standards and Guidelines of Ambient Noise Level In India

Due to the negative effects of rising ambient noise levels in public places from various sources such as activities of the industries and manufacturing, noisy speakers, music systems, vehicular horns, and other mechanical devices on health and psychology of a human-being, the Indian government has taken steps to regulate and monitor noise levels. The central government has made the 'Noise Pollution (Regulation and Control) Rules, 2000' under the Environment (Protection) Act, 1986, for the regulation and control of noise producing and generating sources.

The Central Pollution Control Board of India has set allowable noise standards for towns, as shown in Table 2. These boundaries, however, are broken in all

of India's major cities, with Calcutta being the worst offender. Blaring horns, screeching brakes, and rumbling tyres all adds up to a noisy atmosphere. Accidents on the road add to the suffering.

Table.2'Noise Pollution' (Regulation and Control) Rules, 2000; MOEFCC

AREA	Noise Limits, Leq, dB (A)	
	Day Time	Night Time
Silent Zone	50	40
Residential Zone	55	45
Commercial Zone	65	55
Industrial Zone	75	70

Note: -1. Daytime is described as 6:00 a.m. to 10:00 p.m.

2. Nighttime is described as 10:00 p.m. to 6:00 a.m.

3. A Silence Zone is the 100-meter radius region around hospitals, courts, devotional sites, educational institutes, or any other area designated as such by the competent authority.

4. The competent authority may declare division of areas as one of the four categories listed above.

* The time weighted average of the sound level in decibels on scale A, which is comparable to human hearing, is denoted by dB(A) Leq.

A decibel is a measurement unit for noise.

The letter "A" in dB(A) Leq stands for frequency weighting in noise analysis, which matches to the human ear's frequency response characteristics.

4.8. Sources

Noise sources can be grouped into three types: **transportation**, **industrial**, and **residential**.

Most common sources of noise are automobiles and aircraft, but other vehicles like motorcycles, scooters, and snowmobiles should also be considered. The noise level was increased due to the increase in number of vehicles. Increased traffic has resulted in traffic jams in congested areas, where angry drivers' frequent shouting pierces the ears of all road users. On urban roads, traffic increases during the peak hours i.e. 10 a.m. (morning) and 6 p.m. (evening) as

people commute to and from work. Currently, the noisiest vehicle on the routes is heavy diesel trucks.

Noise coming from airplane is becoming a serious issue in major cities such as Delhi and Mumbai. Airplanes fly over suburban areas from the airport, which is located near population centres. Heavy cars, buses, trains, jet planes, and other vehicles abound, but the end result is the same i.e. noise pollution.

Figure 5: Sources of noise pollution (Source - https://cdn.pixabay.com/photo/2016/09/07/00/25/flyer-1650549__340.jpg and https://upload.wikimedia.org/wikipedia/commons/6/64/Public-address-system.jpg)

Some manufacturing processes and machinery generate a lot of noise. Some examples are the machine tools, high-speed rotating or stamping operations, pneumatic machines, and duct, fan, and blower systems. In industrial towns such as Kolkata, Ludhiana, Kanpur etc., the industrial zones are frequently not segregated from the residential zones, particularly in small businesses. These type of businesses functions from workshops on the ground floors of residential areas, causing frustration, pain, and annoyance to the inhabitants who are subjected to the inevitable noise. In modern planned cities like Chandigarh, the condition was much fine due to the separated industrial and residential by a sufficiently broad green belt.

At first glance, **residential** sources, both indoor and outdoor, may appear insignificant. The outlets namely air conditioners, lawn mowers, dishwashers, kitchen and laundry equipment, television, stereos, pets, and children can also add up to the total noise levels which can't be overlooked. In simple words, increase in the number of tools, gadgets, vehicles, and appliances used in modern industrial societies will result in a significant increase in noise pollution.

The **household** is an industry itself, producing a variety of indoor noises like slamming doors, children's laughter, infants' screaming, furniture movement, and residents' noisy conversations. Aside from that, the house's entertainment devices, such as the radio, record players, and television sets. Indoor sources of noise emissions include mixer-grinders, pressure cookers, exhaust fans, desert coolers, vacuum cleaners, sewing, and washing machines.

Artillery, tanks, missile launches, collisions, war aircraft exercises, and firing ranges all contribute significantly to noise pollution in the atmosphere. Jet engine screams and sonic booms are deafening to the ears, and have been notable to smash window panes and old dilapidated buildings in extreme cases.

Other sources of noise pollution include car repair shops, building sites, drilling, bulldozing, stone grinding, and so on.

Figure 6: Picture showing road repairing site (Source-https://c8.alamy.com/comp/EFM451/construction-workers-are-working-at-the-road-construction-EFM451.jpg)

Rail Traffic: As opposed to the previous forms of traffic noise, rail traffic is less bothersome.

Occupational Noise: For 48 hours a week, industrial employees are subject to a chaotic working atmosphere (8h a day for about 6 days in a week). Millions of staff suffers from progressive hearing loss as a result of their working conditions, making them more vulnerable to injuries. Their productivity is also influenced.

Neighborhood Noise: Loud television and radio sets, loud tape players, loudspeakers at public events, dance music etc. can irritate and annoy the general public, as well as damage patients.

4.9. Effects

Numerous health effects of noise has been characterized such as alterations in the morphology and physiology of an organism which resulted in the impairment of functional ability, capacity to compensate for additional stress, or enhance the susceptibility of an organism to the ill effects of other environmental influences, according to the International Programme on Chemical Safety (WHO 1994).Noise has inherently negative influence and poses a significant health risk. It has wide spread implications and has a variety of physical, physiological, and psychological effects on humans. The implications of noise pollution to one's health will be discussed in this chapter under various headings.

i. Hearing Problems

Humans have five senses, one of which is hearing. As a result, it is an important part of anyone's life. When something becomes noise, it is considered undesirable because it interferes with one's ability to hear.

Figure 7: Hearing issue

(Source-https://pixabay.com/vectors/noise-pollution-anxiety-noise-3583915/)

This is why, when there are a lot of noise, people cover their ears. Hearing damage, including permanent hearing loss, may occur as a result of such loud noise. Long-term exposure to noise levels above 85 decibels is linked to hearing loss caused by noise pollution.

ii. Difficulty in Sleeping

Noise has a psychological impact that can make it difficult to sleep. Noise can disrupt a restful night's sleep by causing tension. Furthermore, being in a noisy environment almost eliminates the possibility of getting some sleep. Inadequate sleep, on the other hand, disrupts the body's normal functioning, resulting in pain, exhaustion, and irritability.

iii. Cardiovascular Problems

The heart is 'excited' by noise. When there is so much noise, the heart is also distracted, and it beats faster, raising blood pressure. Stress hormones like adrenaline and cortisol are released in response to loud noise.

As a result, blood pressure will almost certainly rise in noisy conditions, causing faster blood flow and the release of catecholamine, a hormone that increases the amount of times the heart pumps blood. Normal exposure can keep the body receiving higher impulses, resulting in elevated blood pressure, as long as there is no damage.

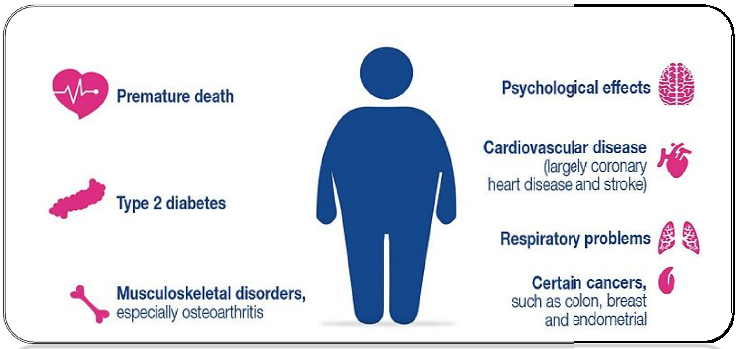

Figure 8: Effects of noise pollution

(Source- https://commons.wikimedia.org/wiki/File:Figure3_digest5.jpg)

If blood pressure continues to rise, it increases the risk of heart-related disorders like high blood pressure and stroke. **Hypertension** and **arteriolosclerosis**, which are caused by pupil dilation and blood vessel constriction, are two other cardiovascular disorders.

iv. Emotion and Behavioral Change

This is not the same as cognitive thought. Too much noise can cause irritation or frustration because it disturbs the peace. People in this state have **chronic** headaches, which can get worse if the noise is constant.

As a result, stress levels may rise, emotions may take over, and aggression may result. Anxiety is said to be the cause of this form of behaviour. Due to the inefficiency of such actions, it becomes difficult to focus on work and achieve set goals.

v. Interference with Speech Communication

Noise-induced speech impairment causes a wide range of personal disorders, handicaps, and behavioral changes. Speech interference is essentially a masking mechanism in which speech is rendered unintelligible due to overlapping, interfering noise.

vi. Annoyance

In a population exposed to environmental noise, the most common response is annoyance. Noise irritation can occur when noise disrupts everyday activities, feelings, thoughts, sleep, or rest, and can be followed by negative emotions such as frustration, displeasure, fatigue, and stress-related symptoms.

vii. Reproduction Problems

Various studies have been performed to estimate the impact of noise pollution on human reproduction, and interestingly, the majority of these studies have concluded that pregnant women who are subjected to noise pollution during their pregnancy give birth to children who are smaller in size. The unborn child is similarly disturbed by the stress levels faced by the expectant mother.

viii. Effect on Wildlife

Since wildlife is more reliant on sound than humans, they face far more problems as a result of noise pollution. Since their life depends on it, animals develop a stronger sense of hearing than humans. Excessive noise has negative consequences that start at home. In a domestic establishment where noise is extreme, pets react more belligerent. They are more easily distracted and have a variety of behavioral issues. Hearing loss is common in nature, making animals easy prey and resulting in declining populations. Others become ineffective hunters, disrupting the eco-balance system. Due to unnecessary man-made noise, species that depends on mating calls to reproduce are often unable to hear these calls.

As a result, they are unable to reproduce, resulting in population decline. While migrating, others rely on sound waves to echo-locate and find their way.

4.10. Control

Understanding the fundamental physics of sound is completely essential for developing a systematic approach to noise control. Since we've covered all facets of noise, the next part of this chapter focuses on noise emissions reduction initiatives.

Control of noise pollution includes the reduction of noise at the source, transmission paths, and protection of the receiver. The control at the source of its generation is preferred. With source noise reduction as top priority, we shall now focus attention on noise control methods.

How to reduce noise pollution

Noise emission is inevitable in some situations. There are, however, methods for reducing noise levels inside the household. It is possible to try:

- **Reducing noise from appliances:** Air conditioners, heaters, fans, and other appliances can all add to the overall noise level in the house. Try turning them off more often or setting a timer so they only turn on when you want them to.
- **Reducing noise from media devices:** Consider how loud music, televisions, radios, and video games are and how long they last. Avoid listening to sounds at too high a volume or making unwanted noise playing in the background for long periods of time. Setting aside time to watch television or listen to music can be beneficial.
- **Repair or replace old machinery:** Older appliances, cars, and other things can make a lot more noise than newer versions. Consider upgrading or replacing any noisy appliances in your home.
- **Soundproofing:** Echo from other rooms, neighbors, or outside may be muffled by strategically placing insulation around the house. Rugs, carpets, and curtains may also be beneficial.
- **Create more quiet time:** Make time for quiet tasks like reading, puzzles, or artistic hobbies on a regular basis. Playing music or making background noise during this period is not recommended.

- **Ear protection:** If noisy noise is inevitable, cover your ears with earplugs or earmuffs.

Figure 9: Control measures of Noise pollution –

a) Earplugs (Source- https://cdn.pixabay.com/photo/2019/10/19/16/44/earplugs-4561728_1280.jpg),
b) No Horn (Source-https://c8.alamy.com/comp/R7W7YT/in-an-attempt-to-reduce-noise-pollution-from-car-horns-official-hand-painted-no-horn-warning-signs-are-installed-around-cites-in-india-R7W7YT.jpg)

- **Go green by planning trees**: We should plant more trees because trees withstand noise well. According to the studies, plants can minimize noise by 5 to 10 dB near their surroundings.
- **Use noise absorbents in noisy machineries**: We should look for machines that make noise due to vibrations and install noise absorbents to decrease the noise.
- **Use proper lubrication and better maintenance:** To minimize noise pollution and increase performance, we should utilize proper lubrication and better machine maintenance. It helps to minimize noise by reducing friction between moving parts.

4.11. Summary

This chapter defines the fundamental concepts associated with sound (and noise), and readers should now understand noise – its causes, effects, sources, control measures, and so on. This chapter discusses the characteristics of noise as well as how sound propagates through a medium and its effects.

. We've learned about different sources of noise pollution. Noise pollution standards are also considered. Noise has a variety of effects on people, discussed in the chapter. It leads to improper communication, insomnia, and decreased productivity. The consequences of noise pollution must be taken seriously. Finally, the chapter emphasizes that control measures such as

planting trees around the noisemaking facility are practically easy to implement in order to diminish environmental noise.

TERMINAL QUESTIONS

1. What is noise? Also write its sources.

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2. Define: Amplitude, frequency and wavelength

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3. Explain sound level meter.

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4. Explain weighting networks of sound level meter?

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5. Explain the sources and consequences of noise pollution?

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6. What are the measures needed to control the noise levels?

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ANSWERS

1. Noise may be defined as unwanted sound which is derived from the Latin word "nausea" means 'unwanted sound'.

Hint: Noise sources can be grouped into three categories: transportation, industrial, and residential.

2. *Amplitude*- The maximum amount of displacement of a particle on the medium from its rest location is referred to as the amplitude of a wave.

Frequency- Frequency is the number of cycles repeated in a given amount of time. Cycle/sec or Hz is the unit of measurement (1 Hz= 1 Cycle/sec).

Wavelength- The wavelength of a sound is the measurement of the distance between two adjacent equal parts of a wave.

3. See Page no. 6
4. See Page no. 7
5. Source of noise pollution are the activities from where it comes i.e. transportation, domestic or commercial activities and it affects the mental health of a living organisms i.e. hearing disorder, annoyance etc.

It can be controlled by reduction at its source and their transmission pathways and also by protecting the exposed well being.

Unit 5: Water Pollution: Definition and types, classification of water pollutants; fresh water and marine water pollution and their sources; Transformation in nature and water quality

Unit Structure

5.0. Learning objectives

After studying this unit, you will be:

- Familiar with the concept of water pollution
- Identify the sources of water pollution
- Recognize the different types of water pollution and the different pollutants responsible for causing water pollution
- To differentiate between fresh water and marine water pollution and to recognize their sources
- Well versed with the effects caused by polluted water in environment and man which include eutrophication, algal blooms, effects on human health.

5.1 Introduction

Planet Earth looks blue when seen from space as it contains 70% of water and 30% land mass. Out of the total water present, only 0.002% of water is available for human consumption, other industrial and domestic activities, rest is unsuitable or unavailable for use as 98% of water is marine and brackish and the remaining percentage is locked up in glaciers and ice caps. Due to rapid population growth, industrialization, urbanization, green revolution, our dependence on water resource has increased manifolds resulting in their exploitation and degradation. As per WHO reports, 1.1 billion people across the globe does not have access to safe water and are facing water security issues. Both surface and ground water have been contaminated due to discharge of untreated pollutants from industries, domestic sewage, agricultural runoff in the form of chemical, physical or biological waste adding thousands of pollutants into water bodies as a result of ignorance by general public, or industrial and authorities.

Effluents from industries, food processing units, waste from hospitals, domestic sewage, research laboratories, etc discharge ample amounts of heavy metals, microbes, pathogens, dyes, pharmaceuticals, detergents etc directly or indirectly into water bodies causing health effects to humans and ecosystem. The toxic chemicals may bio-accumulate in aquatic organisms and then affects the terrestrial ecosystem as well through food chain.

In this unit, you would find certain terms and concepts that you have studied earlier regarding water pollution. The concepts of water pollution have been elaborated in detail.

5.2. Water Pollution: Definition and types

The undesirable change in the physical, chemical and biological characteristics of water is water pollution. Water pollution happens when some unwanted materials enters the water bodies like ocean, seas, rivers, lakes, ponds etc. mainly because of human interventions and alters the general characteristics of water. This degrades the quality and health of the water body. Not only does

this spell disaster for aquatic ecosystems, the pollutants also seep through and reach the groundwater degrading its quality too. The pollutants present in both surface and ground water might end up in our households as contaminated water we use it in our daily activities, including for drinking purpose.

5.2.1 Types of water pollution

Water pollution can be broadly categorized into eight types depending upon location and type of water

a) Ground water
b) Surface water
c) Ocean water
d) Point source
e) Nonpoint source
f) Trans-boundary
g) Agricultural
h) Sewage and waste water

a) Groundwater Pollution

This type of pollution happens when the ground water gets contaminated or polluted by the contaminants released from both point and non-point source. The type of pollution isa matter of concern as it affects our drinking water and the aquifers below the soil (see Fig. 1). The polluted water seeps through the pores present in soil and ultimately reaches the aquifers (water holding sediments) and affects the ground water. Contamination of ground water is more serious issue as compared to surface water, as contaminants when they reach ground water particle, remain there for at least 10,000 years. Groundwater pollution is usually caused by leaching and percolation of highly toxic chemicals like pesticides, fertilizers from agricultural farms, seepage of dumped waste, improperly managed septic tanks into aquifers present below the surface.

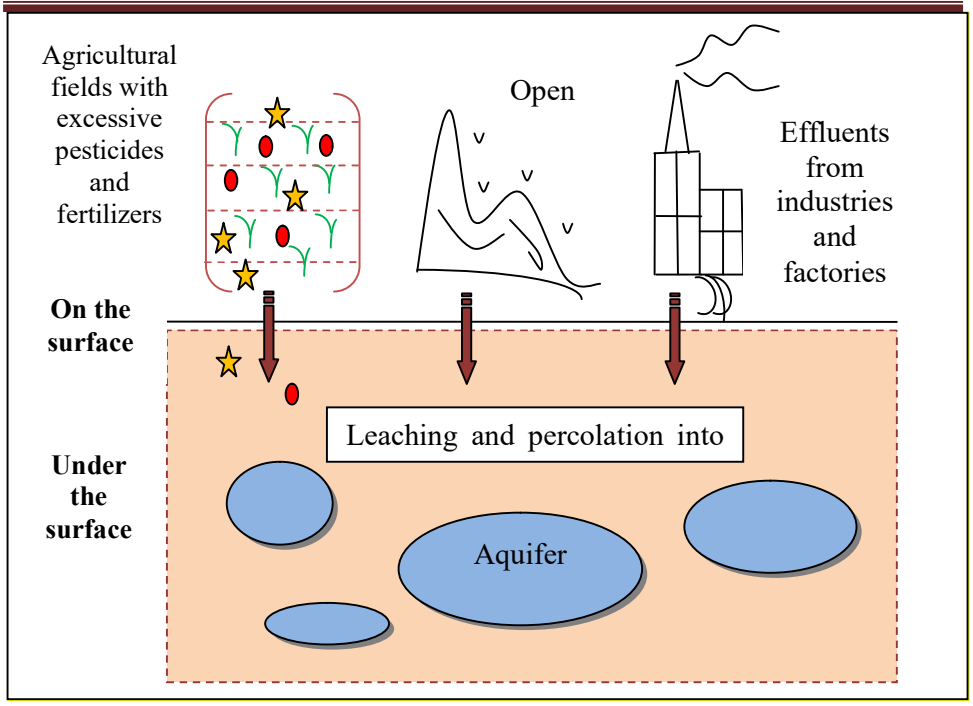

Fig. 1 : Ground water pollution

b) Surface Water Pollution

When the surface water in the form of lakes, rivers, streams, ponds and oceans gets polluted with hazardous and unwanted substances it is known as surface water pollution. Surface water has been exploited by humans for various purposes: as these are considered as best dumping sites for industrial and domestic waste, used for irrigation, recreational activities etc. Surface water pollution is the most visible form of pollution as we can witness it by the presence of trash, plastic, floating on our waters in lakes, rivers, streams, and oceans, undesirable changes in the colour, smell and taste of water. Trash from human consumption, such as water bottles, plastics and other waste products, is most often evident on water surfaces. Foaming from waste water treatment plants also find their way to river channels. The type of pollution also occur because of oil spills and as a result of oil mining in oceans resulting in great loss to the aquatic inhabitants and water birds by casing their mortality at an alarming rate.

c) Ocean water pollution

Origin of more than 80% of ocean water pollution is on land. Huge amounts of contaminants such as chemicals, nutrients, organic waste, heavy metals, dyes

are carried from industries, factories, agricultural activities by means of rivers and streams and ultimately drained into the oceans and seas. Marine debris particularly plastic is either carried through storm drains or sewer system or are blown through winds. Construction and demolition waste is also dumped into the ocean water. Ocean water also suffer from oil spills during accidental cargo-ships collision or accidental leakage.

d) Point source water pollution

It is any single identifiable source such as a pipe ditch, ship or factory smokestack from which pollutants or effluents are discharged directly into water bodies. In other words, pollution from a single source is called point source pollution. It is quite east to keep a check on these point sources of water pollution. Examples of point sources include:

i. discharges from wastewater treatment plants;
ii. untreated effluents from factories and industries;
iii. Combined sewer outfalls.
iv. Domestic sewage etc.

e) Non-point sources

Non-point sources of pollution generally results from land runoff, precipitation, atmospheric deposition, drainage, seepage and hydrologic modification and generally are not specific in nature, rather scattered or stretched over large area i.e., pollutant in this case comes from many diffuse sources. These include:

i. Excess fertilizers, pesticides release from agricultural lands through runoff
ii. Oil, grease and toxic chemicals from urban runoff and energy production units
iii. Sediment from improperly managed construction sites, barren lands, eroding stream banks
iv. Salts from unmanaged irrigation practices
v. Acid mine drainage from abandoned mines
vi. Bacteria and nutrients from faulty septic systems, livestock, pet wastes etc.

Non-point source pollution is the leading cause of disrupting water quality by adding majority of contaminants in water bodies.

f) Trans-boundary water pollution

As the flowing water cannot be contained by a line or a boundary, so is the pollution of water. The polluted water from one country flows to another country thereby polluting the water of other countries also. The examples of trans-boundary water pollution are: oil spills, the industrial, municipal or agricultural waste discharge into rivers or streams flowing downstream to other countries.

g) Agricultural

Agriculture sector is the biggest consumer of freshwater resources as farming, livestock production depends entirely on the freshwater resources. At the same time, it is also a serious water polluter as it is a leading source of contamination of rivers and streams. Fertilizers, pesticides, animal wastes from livestock operations, add nutrients and pathogens to the water bodies through runoff. The excess of nitrogen and phosphorous results algal blooms and eutrophication causing harm to the aquatic ecosystem and the water quality.

h) Sewage and wastewater

Used and discarded water is wastewater. Water from kitchen sinks, showers and toilets, spend water from industrial, commercial, agricultural and municipal activities adds to wastewater. The waste water from municipal activities in particular is sewage. It is estimated that about 80% of the world's wastewater flows back into the environment without prior treatment. Prior treatment facilities reduce the amounts of pathogens (bacteria, viruses), nutrients like nitrogen and phosphorous present in the wastewater. Release of untreated sewage and wastewater from industrial, commercial, municipal and agricultural activities leads to degradation of water quality.

5.3. Classification of water pollutants

Pollutants in marine water and fresh water are almost similar. Industries and factories alongside the water bodies, direct its waste water towards rivers, lakes, oceans and seas, introducing loads of pollutants which escape waste water treatment facilities like heavy metals, organic and inorganic compounds,

emerging contaminants like nanomaterials, lesser known chemical compounds. As oceans are regarded as dumping sites, huge amounts of solid waste consisting of construction and demolition waste is also as dumped into water bodies. However, hydrocarbons and plastic are regarded as chief pollutants causing water pollution with marine water in particular.

a) Organic load

Nutrients like nitrogen and phosphorous from agricultural runoff adds organic load to the water bodies. Organic matter, fecal matter also adds organic load in the water bodies.

b) Heavy metals

The major concern with water pollution is the presence of heavy metals due to release of effluents from industries and agricultural activities. Different industries release heavy metals like Arsenic, lead, mercury, cadmium, chromium, copper into the waterways. These heavy metals are toxic to aquatic ecosystem as well as cause toxicity to humans also.

c) Dyes

Dyes are highly carcinogenic chemical substances found in water ways. They are considered as one of the major culprits for waste water generation, as it contains highly toxic substances in it. The dying process produces large environmental problems throughout the discharge of their effluents

d) Plastic

Debris of plastic in aquatic environment is of global concern as tonnes of plastic lie in ocean bottom and floating in oceans. Both forms of plastic i.e. macroplastic (>5mm) and microplastic (<5mm) reach marine environment through rivers or through direct dumping into marine water. Plastic bags, plastic ropes are the chief contributor of marine pollution and large number of marine animals including fish, turtles, seals, sharks gets entangled into it, affecting their mobility. Marine organisms even swallow these plastic bags resulting in death of these organisms. As plastic waste does not degrade, it enters the food chain and reach to humans through sea food.

e) Hydrocarbons (oil spills)

Hydrocarbons in the form of crude oil spills in ocean or sea due to anthropogenic activities such as on shore or offshore mining for the extraction of oil from oil reserves located in oceans, or due to accidental release of oil from cargo ships. Hydrocarbons exhibit deleterious effects on all kinds of marine wildlife including marine invertebrates, higher forms of life and sea birds. As oil forms emulsion on the water surface, hence do not dissolve and floats over the surface thereby blocking the entry solar radiations into oceans. As a results of this, there is creation of anoxic conditions in marine water, suffocating the inhabitants. The effects of oil spillage is most prominent in marine aquatic organisms as their coetaneous surface is in direct contact with oil and also hinders the flight abilities of sea birds.

5.4. Fresh water and marine water pollution and their sources

Surface water can be broadly categorized into two categories: Fresh water and marine water. Fresh water is the water in rivers, streams, lakes, ponds etc. and water in oceans and seas is marine. Both these categories of surface water differ from one another in terms of salt content. The salt content of fresh water is <0.5 ppt (Parts-Per-Trillion) whereas, salinity of marine water is 35 ppt. The pollution of both fresh water as well as marine water are discussed below:

5.4.1. Fresh water pollution

Fresh water is an indispensable resource for the success of a nation in terms of economic development. Hazardous chemicals from industries, domestic and agricultural runoff bringing about undesirable changes in the physical, chemical and biological wellbeing of any inland water including rivers, lakes, ponds, streams is termed as fresh water pollution. Rivers and streams play prominent role in assimilation, carrying off, dissolution and dilution of municipal, industrial and domestic wastewater. The land use change also marks a prominent role in causing fresh water pollution as construction and developmental activities like barriers across the river channels, diversion of streams for irrigation purpose, or dredging of water banks affects the various components of water thereby reducing its quality.

5.4.2. Sources of freshwater pollution

The main causes responsible for making fresh water polluted are listed below:

a) Domestic/Municipal sewage

Domestic sewage is the wastewater arising from domestic and community activities like cooking, washing, bathing etc. It is also municipal wastewater. Domestic sewage is characterized by the presence of high pathogen load, toxic materials like heavy metals, chemical substances like pesticides, high organic matter, nutrient load, dissolved minerals. Water pollution by sewage water occurs because of lack of proper functioning and management of wastewater treatment plants.

b) Religious activities

Water bodies have a direct connection with religious activities as rivers, lakes and ponds are considered ideal for carrying ritualistic activities. Mass ritualistic bathing, idol immersion is generally carried in rivers. During religious festivals, large amounts of materials like flowers, sweets, earthen lamps and pots, leaves, seedlings, coins etc are added to water bodies thereby increasing the organic matter, nutrients and other materials. Dead bodies, or bones after cremation are also immersed in water bodies contributing to pollution.

c) Industrial waste

Effluents coming from industries, wastewater treatment plants, drainage pipes, unloads ample amounts of noxious chemicals, heavy metals like lead, arsenic, mercury, pathogens, nutrients thereby increasing the organic matter content, biological oxygen demand and chemical oxidation demand of that concerned water body. Undesirable changes in water temperature also leads to water pollution. Industries also use water from rivers or ponds as coolants and in turn dispose off hot water directly into rivers or streams without minimizing its temperature. This brings sudden rise in river water temperature resulting in harmful effects to aquatic ecosystem as aquatic organisms are very sensitive towards temperature fluctuations.

d) Pharmaceuticals

Large number of micro pollutants also known by the term emerging contaminants of concern find their directly into fresh water. One such category of emerging contaminants is pharmaceuticals. These chemicals are generally administered for curing, treating and prevention of diseases and for diagnostic purpose. These are used extensively worldwide and include antibiotics, synthetic hormones, anti-inflammatory compounds etc. These chemicals are of a great concern as these reach water bodies directly or through improperly managed domestic effluent waste water treatment plant and greatly affect the aquatic organisms even at very minute concentrations. These when enter the aquatic ecosystem adversely affect the living organisms.

e) Agriculture

Apart from the different pollutants discussed above, agriculture have been considered as one of the principal cause of water pollution as per recent assessments carried out globally. Agriculture is being responsible for the discharge of huge amount of organic matter, nutrients, agrochemicals, sediments etc. into water bodies thereby degrading its quality. Agriculture depends on water requirement which is mainly fulfilled by irrigation. For providing water for irrigation, river water is directed into small irrigation channels which results in reduction of water flow in the main water bodies reducing their dissolution efficiency further intensify pollution in water.

5.4.3. Marine water pollution

About 98% of water available on earth is marine water with high salt content. Water in seas and oceans is considered as marine water. This water is not fit for drinking, agricultural and industrial activities. So, seas and oceans are considered as dumping sites by humans. Humans dispose of trash, waste from industrial, mining and construction activities into oceans bringing undesirable changes in the quality of marine water.

Pollution of marine is caused by the introduction of unwanted, discarded, toxic, radioactive substances into marine environment by anthropogenic activities resulting in deleterious effects on human health, living organisms

and causing hindrance to marine activities including fishing, affecting the water quality of seawater.

5.4.4. Sources of marine water pollution

Industries and factories alongside coastal areas direct its wastewater towards oceans and seas, introducing loads of pollutants which escape wastewater treatment facilities like heavy metals, organic and inorganic compounds, emerging contaminants like nano materials, lesser-known chemical compounds. As oceans are regarded as dumping sites, huge amounts of solid waste consisting of construction and demolition waste is also as dumped into marine water. For marine water pollution both natural and anthropogenic factors are responsible. The natural sources include deep sea volcanic activities, spontaneous releases of natural oils inside oceans. At many cases, a number of accidental cases are also responsible for this dispute. Ship, boat, fishing vans running over large marine water bodies sometime gets damaged by unavoidable accidents, so that, it releases a huge amount of toxic chemicals of containing poisonous oil. High tourism activities, and their impact like of solid waste into the oceans increases pollution level. The industrial release toxic effluents also increase the pollution level to many extents. These poisonous oils are nothing but are highly injurious for the aquatic organisms to sustain a quality life.

SAQ 1:

In the following statements, write true (T) against the correct ones and false (F) against the wrong ones.

(i) Excess fertilizers, pesticides release from agricultural lands through runoff constitute point source pollution ( )

(ii) Discharge from wastewater treatment plants is an example of point source ( )

(iii) Excess of nutrients adds to water quality ( )

(iv) Presence of hydrocarbons in water increases the amounts of solar radiation penetration into water bodies

5.5. Transformation in nature and water quality

Polluted water results in wide range of issues to environment, ecosystem and to human health. A pollutant in water brings about undesirable changes in the aquatic environment. Some of these changes are as follows:

5.5.1 Eutrophication

Standing water bodies particularly lakes and ponds are often characterized by the presence of green mat like structure floating on its surface. Presence of such feature is called **eutrophication** and occurs because of enrichment of nutrients like **phosphorous** and **nitrogen** in the water bodies (see Fig. 2). Eutrophication presents as one of the most serious ecological problems of open water sources such as **lakes and reservoirs**. Excessive amounts of phosphorous and nitrogen results in the formation of extensive mats of floating plant-most common are algae, water hyacinths etc. Eutrophication is the phenomenon associated with fresh water bodies. The water body having eutrophication is considered to be polluted and the excess growth of algae over the surface of water blocks solar radiation penetration into the water body, creates anoxic condition in the water body resulting in death of other aquatic organisms.

The contributor of major nutrients (nitrogen and phosphorous)in water bodies are animal wastes, fertilizers and sewage which are washed by rain or irrigation into the water bodies through surface runoff. Process of eutrophication can also occur naturally over thousands of years as the process of ecological succession takes place and lakes get filled with sediments which are rich in nitrogen and phosphorous. Human activities accelerates the degree and rate of eutrophication through nutrient discharge into water systems by both point-source and non-point sources.

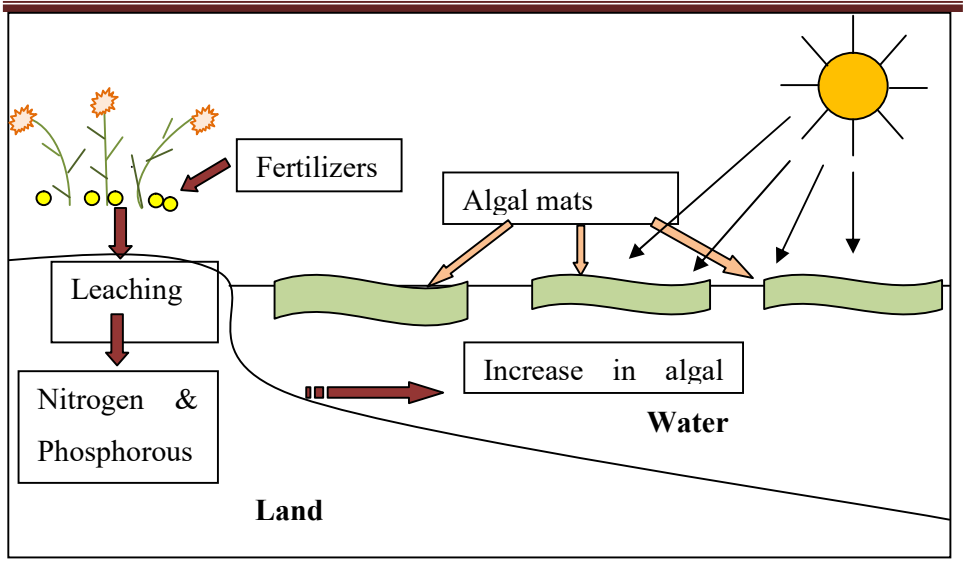

Fig. 2 : Illustration of Eutrophication

5.5.2 Algal Blooms

Algal blooms are the result of excessive growth of various types of algae in marine environment because of excess supply of nutrients mainly nitrogen and phosphorous. Excess of nutrients in seas and oceans are a result of anthropogenic activities like sewage discharge having loads of organic matter and nutrients and contribute to major environmental problems. Algal blooms and eutrophication are same. The only difference that lie between the two is the type of water where the process takes place i.e., marine water or freshwater. Algal blooms is the excessive growth of algae in marine water because of availability of excessive nutrients needed for their growth. Formation of Algal blooms is a threat to aquatic ecosystem as some algae produce dangerous toxins in marine water and also forms dead zones in oceans. Harmful algal blooms can be green, blue, red or brown in colour as the various types of algae possess different pigments. Red sea, Pink lake are because of presence of coloured algae. Algal blooms can be scummy or look like paint on the surface of the water.

Algae adds large amount of organic matter when they die. In order to decompose organic matter, requires the involvement of aerobic micro-organisms. This will accelerate the demand for oxygen to biologically break down the organic matter. As the water is already deficient of oxygen because

of thick mats of algal growth floating on the water surface, will further create anoxic conduction, causing suffocation to fish and other marine life.

5.5.3 Bio-accumulation and bio-magnification

Toxins have become progressively more ubiquitous in our modern industrial world. Toxic substances present in industrial and domestic waste disposed off in water bodies end up in humans via food chain. In every ecosystem, organisms are intricately interconnected through food chains and food webs. Wide variety of toxic chemicals and hazardous substances like heavy metals (lead, arsenic, mercury, cadmium etc.), Polychlorinated biphenyls (PCBs), Poly aromatic hydrocarbons (PAHs), nanomaterials, personal care products, pesticides (e.g. DDT) etc finds their way into aquatic organisms. Humans gets exposed to these toxins directly by consuming polluted water or by food chain through the consumption of contaminated fish or other sea food. Once the aquatic organisms consumes these toxins, they build up in their fat tissues as these are fat soluble and does not pass out of their body during excretion and keep on accumulating in their body fats - a phenomenon called **bio-accumulation**. The accumulated toxins then passes to organisms of higher levels in food chain and their amount magnifies at each trophic level - a process called **bio-magnification**. Through food chain, the toxins from aquatic ecosystem enters the terrestrial ecosystem causing deleterious effects to the organisms in terms of their mortality, reduction in their population growth and also affects the entire ecosystem.

5.5.4 Water quality standards

Water is characterized by presence of physical, chemical and biological components which are to be present in certain limits as prescribed by certain organizations indicating the quality of water. Quality water is necessary for good human health. Colour, odour, temperature, electrical conductivity, pH, dissolved oxygen, alkalinity, hardness, total solids, cations and anions like chloride, nitrate, sulphate, calcium, magnesium, potassium, sodium etc are considered as water quality parameter and need to be present in certain amounts. Their presence in excess amount than their prescribed acceptable limit but within permissible limit indicates the water to be **contaminated**

whereas their presence in amounts exceeding the permissible limits indicates **pollution** of water.

Various standards have been put forward by different organizations describing the quality of water. If the amount of constituents exceeds the desired limit, that water is considered polluted. World Health Organization have prescribed standards for drinking water (see table. 1).

Table. 1 : W.H.O drinking water standards

Parameter	Unit of expression	limit
Arsenic (As)	milligrams/litre or ppm	0.05
Cadmium (Cd)	microgram/litre or ppb	5.0
Chromium (Cr)	milligrams/litre or ppm	0.05
Copper (Cu)	milligrams/litre or ppm	1.0
Lead (Pb)	milligrams/litre or ppm	0.01
Mercury (Hg)	microgram/litre or ppb	1.0
Cyanide (Cn)	milligrams/litre or ppm	0.1
Fluoride (F)	milligrams/litre or ppm	1.5
Nitrates (NO_3)	milligrams/litre or ppm	10.0
Hydrocarbons	milligrams/litre or ppm	0.1
pH		9.2
Total dissolved solids	milligrams/litre	1500
Total hardness	milligrams/litre	500
Alkalinity	milligrams/litre	500
Total bacteria	Count/ml	100
Coliform	Count/100ml	0
E.Coli	Count/100ml	0

Source : Bharathy, 2018

5.5.5 Effects of degraded water quality on human health

Consumption of polluted water exposes humans to many water related problems. It is reported that approximately 30% of gastrointestinal diseases are water related. Water borne diseases are prevalent in developing countries which lack proper hygiene and sanitation and lack access to safe drinking water. Various bacterial, viral, protozoal diseases related with water pollution are hepatitis, typhoid, dysentery, giardiasis, cholera. Apart from these diseases, there exists several disorders associated with consumption of polluted water. Excess of fluoride in water causes dental and skeletal fluorosis, nitrates cause methamoglobinemia (blue baby syndrome), arsenic cause skin lesions, diabetes, cancer etc.

SAQ2

I. Match the most appropriate

	Parameter			Effect
a	Fluoride	:	i	Cholera, dysentery, typhoid
b	Nitrogen and phosphorous	:	ii	Dental and skeletal fluorosis
c	Arsenic pollution	:	iii	Blue baby syndrome
d	Nitrate	:	iv	Eutrophication
e	Pathogenic microorganisms	:	v	Skin cancer

II. Answer the following questions

1. What do you understand by Bio-accumulation?

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2. Name the nutrients responsible for causing algal blooms.

5.6. Summary

In this unit, we have learnt in detail about water pollution. So far you have learnt that:

- The undesirable change in the physical, chemical and/or biological characteristics of water is water pollution; caused mainly by the anthropogenic activities.

- The generalized sources of water pollutants are point-source and non-point source.
- The main source of water pollution is agricultural discharge, sewage (waste water) from domestic and industrial processes, radioactive wastes, pathogens, hydrocarbons (oil), plastic waste etc.
- The increase in water pollution is harming our food supplies, drinking water and environment.
- Eutrophication is the excessive richness of nutrients in a lake or other body of water, frequently due to run-off from the land which cause a dense growth of plants and algae, mainly due to the enrichment of nitrogen and phosphorous.
- Bioaccumulation is the built up of chemicals such as heavy metals and polychlorinated biphenyls, pesticides etc. inside of fatty tissues of living organisms.
- Water pollution can be controlled by treating the waste water in treatment plants before discharging it in water bodies.
- Wastewater treatment involves physical, chemical and biological treatments to remove all the contaminants from waste water.
- Treatment processes involved in wastewater plant are sedimentation, floatation, filtration, membrane separation etc.
- Water quality standards are the criteria that describes the quality of water.

5.7. Glossary

Algal blooms	:	Excessive algal growth in oceans or sea because of excessive nitrogen and phosphorous
Aquifers	:	Water holding rock formations
Bio-accumulation	:	Gradual accumulation of toxins in the animal fat tissue
Bio-magnification	:	Amplification of toxins in successive higher order in food chain
Effluent	:	Liquid waste discharged from factory outlet pipes into any water body

Emulsion	:	A mixture of two unmixable liquids
Eutrophication	:	Excessive algal growth in freshwater due to availability of excess nutrients
Nanomaterials	:	Materials in the nano dimension scale
Pollutant	:	Physical, chemical or biological factor causing detrimental effects on life and property
Sewage	:	Waste water from domestic or municipal activities
Waste water	:	Water that results from domestic, industrial activities

Possible answers to SAQs

True - false

i. (F)
ii. (T)
iii. (F)
iv. (F)
v. (T)
vi. (T)

Match the following

Parameter Effect

a	ii
b	iv
c	v
d	iii
e	i

Answer the following

1. Bio-accumulation : Hint (See 1.8.3)
2. Nitrogen and phosphorous

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TERMINAL AND MODEL QUESTIONS

Short answer type questions

1. Define water pollution. Enlist its main sources.
2. Write a short note on non-point sources of water pollution.
3. What do you understand by Eutrophication?

Medium answer type questions

1. Explain the point and non point sources of water pollution.
2. What are the various types of water pollution?
3. Explain the various effects of water pollution on environment.

Long answer type questions

1. Explain in detail the control and management of water pollution.
2. Elaborate the concept of ocean acidification and bioaccumulation.
3. Explain in detail the various types, sources and effects of water pollution.

Unit 6: Effects and Control of Water Pollution: Effects on water ecosystem, water life and human beings; Control measures

Unit Structure

6.0. Learning objectives

After understanding this unit we would be able to:

- Explain water pollution
- Identify and enlist various sources of water pollution
- Be familiar with different types of water pollution
- Know about effects of water pollution on water ecosystem, water life and human-beings
- Know how to control water pollution
- Have knowledge about waste water treatment techniques

6.1 Introduction

Water is the first obligatory resource that earth provides to sustain life. Without water any living organism would not be able to survive on this earth. Water plays a major role in life of every organism by fulfilling their thirst and many other needs. The earth so called “blue planet” because of the fact that about 71% of its surface is covered with water. Inspite of such abundance of

water on earth, only a small fraction about 0.3% is useful to human. The rest 99.7%is unfit for drinking and locked under snow, icecaps, glaciers, oceans, etc. Although that 0.3% fraction water is sufficient to sustain life or can meet the needs of living organisms but contamination or pollution of water is a serious threat to useful fraction of water. Water pollution results due to addition of any chemical/foreign substances in the water bodies to such an extent beyond which the water can become unfit for specific purposes like drinking, cooking, bathing, etc. In addition to that water pollution also extends its toxic effects to living beings as well as environment. Humans also suffer from several water borne diseases after drinking or coming in contact with polluted water. Water is often generally known as a universal solvent in liquids present on earth by virtue of its property to dissolve a variety of substances in it than any other liquid. Because of this ability, water is exclusively susceptible to pollution as it can readily dissolve foreign/toxic chemical substances discharged into it and mix with it, causing water pollution by degrading water quality.

6.2. Water pollution

Water pollution involves the occurrence of any foreign harmful substances such as chemicals or microbes resulting in contamination of water bodies i.e. streams, rivers, lakes, oceans, groundwater, aquifers, etc., thereby deteriorating water quality and rendering it toxic to humans, plants and animals leading to overall environmental health degradation. Therefore, water pollution may be defined as the condition when water become unsafe to drink, unfit for usage, impose toxic effects which results due to change in water quality accompanied by introduction of any foreign material into the water bodies. Such materials are commonly termed as water pollutants which possess capability to deteriorate water by altering the physical, chemical or biological characteristics of water. These polluting substances may come from a variety of sources include some specific sources including several kind of industrial waste, municipal waste, animal farms, feedlots and some non-specific sources including storm water, agricultural runoffs, construction works, mining activities and many more.

6.2.1 Water pollutants and their types

Any substance with potential to alter the physical, chemical or biological characteristics of water that subsequently have negative consequences on living organisms as well as the ecosystem or environment. These may include any physical component such as heat, oil, garbage, debris, etc. that alter physical characteristics like temperature, turbidity and other, any chemical component such as fertilizers, pesticides, various organic and inorganic compounds, or any biological component such as pathogenic microorganisms like bacteria, virus, protozoan.

Types of water pollutants

Water bodies receive mainly six types of pollutants including:

1) Organic pollutants

These include the waste contributed by domestic, municipal and commercial sewage, effluents from textile and paper mills, food processing units, dairy farms, poultry farms, petroleum refineries, piggeries, breweries, tanneries, etc. Water enriched with these wastes commonly called as community waste waters. Such type of waste is responsible for polluting rivers, streams, etc. River Ganges is severely polluted due to dumping of these kinds of organic wastes into it.

2) Inorganic pollutants

These include chemical wastes/effluents discharged from industries, agricultural run-offs, bathroom water and toilet wastes, oil spills, etc. Industrial effluents comprises toxic inorganic compounds like alkalies, cyanides, acids, salts besides some toxic metals like arsenic, mercury, lead, copper, zinc, cadmium and many other. Bathroom waste water comprises soaps and detergents while agricultural waste run-off comprises phosphates and nitrates fertilizers, insecticides herbicides, pesticides, etc. All of these pollutants pose harmful impacts on health of all living organisms.

3) Pathogens

These are the pathogenic microbes including bacteria, virus, protozoa, helminthes eggs, etc. Introduced into water bodies from domestic sewage. These organisms are capable of causing deadly diseases like cholera typhoid,

dysentery, hepatitis, and many more. With the help of flowing water of river, these microbes can be carried to other places and spread disease causing germs to wider areas.

4) Heat

It is the physical parameter that is responsible for altering the water quality and disrupting life inhabiting the water bodies by raising the water temperature. More likely reason for addition of heat into water bodies is the waste heat discharge from nuclear and electric power plants. Water is the only sink for power plants to dispose of the high temperature effluents generated in the plants. High temperature results de-oxygenation in water which severely affects aquatic flora and fauna.

5) Suspended matter

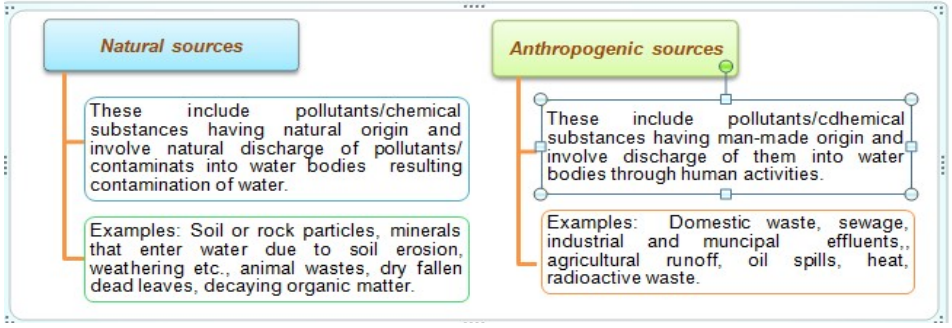
These are the pollutants that do not mix with or dissolve into water. These include sediments or soil particles eroded by rain, silt, mud, tiny clay particles, dust and other. These are responsible for making water turbid. Turbidity of water also affects aquatic life by reducing penetration of sunlight for photosynthesis aquatic plants which results in reduction of photosynthesis and disturbing the food chain ahead.

6) Radioactive waste

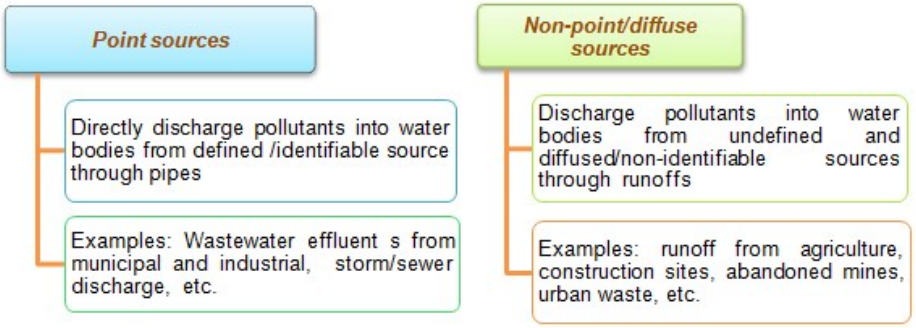
Radioactive waste include radio nuclides like uranium, radium, etc. generated in nuclear power plants and radioactive dust from mining and processing of uranium and other radio nuclides. These wastes disposal into water bodies leads to degradation of aquatic environment by radiating harmful radiation and often leads death of aquatic flora and fauna.

6.2.2. Sources of water pollution

Water pollution occurs due to discharge of pollutants from different sources into water bodies. Depending upon the origin and diffusion or mode of waste/pollutants discharge into the water bodies, different kinds of water pollution sources are there. On the basis of origin of pollutants, there are two sources: natural sources and anthropogenic sources.



On the basis of diffusion or mode of waste/pollutants discharge into the water bodies, there are two types of water pollution/pollutants sources: point sources and non-point sources.



6.2.3. Types of water pollution

Water pollution generally categorized into four major types:

1) Surface/inland water pollution

Surface water can be defined as the water having natural occurrence on the earth's surface. They include rivers, lakes, lagoons, streams. Contamination of such water features takes place through introduction of pollutants accidently or intentionally. Most of the industries such as paper and steel industries dumped down their wastes including dyes, alkalies, acids and other toxic chemical as effluents into water bodies like rivers. Aluminium manufacturing industries release huge amount of fluoride, fertilizer industries discharge ammonia, steel plants contribute cyanides to water, pesticides like Aldrin, Dieldrin, DDT, Malathion, Parathe in from agricultural runoff drift down in low lying water areas and many more industrial units provide their effluents a way to water and finally disrupt the aquatic ecosystem and harmfully affect on health of human and other living organisms. Surface/inland pollution takes place on

land and also leads to ground water contamination by leaching out of contaminants through soil into groundwater. Rainwater also accelerates the groundwater contamination to large extent. This type of pollution causes more health damages to every living organism including plants, animals and human beings living on this earth along with ecosystem health damage.

2) Groundwater pollution

On application of chemicals like fertilizers and pesticides to soils in order to promote crop growth, certain residual chemicals washed deep into the ground with the aid of rainwater which ultimately lead to infiltration of them into underground water by crossing the water table and hence resulting groundwater pollution/contamination as represented below in fig.1.

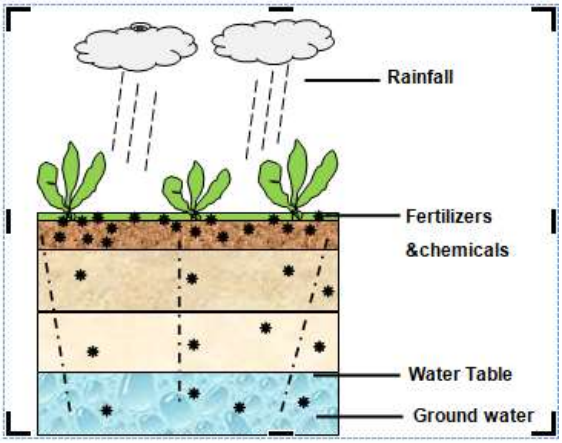


Figure 1: Infiltration of chemicals and fertilizers through soil into groundwater

3) Thermal pollution

Various power plants like thermal power plants, nuclear power plants and industries discharge of their waste heat into water and results increase in temperature of a water body that leads to adverse changes in it. Such undesirable changes due to rise in temperature in water bodies called thermal pollution. Heat causes depletion of dissolved oxygen in water. High temperature in water bodies speeds up the metabolic activities of organisms thriving there which lead to more oxygen consumption by microbes. Therefore, due to depletion of oxygen, many of the aquatic organisms die. Other effects includes difficulty in migration of aquatic organisms because of formation of various thermal zones, high temperature causes increase in toxicity of chemicals and particles present in the effluents discharged in water, etc.

4) Marine pollution

Also called as ocean or sea water pollution. It involve every kind of pollutants generated everywhere on this earth. Oceans and seas provides a natural sink to a number of contaminants produced on this earth and each one find its way finally to arrive at ocean or sea. These contaminants can be any garbage, domestic waste, sewage, plastics, radio nuclides, grease, oil and much more.

6.3. Effects of water pollution

Contamination of water bodies with industrial effluents, agricultural runoffs, domestic and municipal sewage and many other sources has affected both terrestrial and aquatic life on earth. Every living organism inhabiting any ecosystem depends on water for their survival and thus severely influenced in consequence of utilizing polluted water. Some of the adverse effects of water pollution on water ecosystem, life inside water and human health can be understood from below sections.

6.3.1 Effects on water ecosystem

There are a variety of devastating effects that the polluted water results on water ecosystem. Few of them are described as:

A) Disruption of food chain

Water provides habitat to a number of organisms known as aquatic organisms ranging from microscopic ones e.g. phytoplankton to larger one e.g. whales. All of these aquatic organisms inhabiting water body depend on one another for food and other necessities by forming an aquatic ecosystem. This ecosystem comprises a number of interconnected networks for called food webs which are formed of a variety of food chains. Therefore, any harm to an organism living in an aquatic ecosystem belonging to a particular food chain may disrupt entire ecosystem immediately or after a certain period of time. Consumption of contaminated water by living organisms dwelling inside a water body can directly or indirectly cause several health damages to them and sometimes may lead to death which might affect the subsequent organisms or predator that solely depend on the former for food. This type of contamination may happen to a number of organisms in all kind of food chains in that particular aquatic ecosystem and the predators or organisms free from contamination may suffer from severe appetite due to unavailability of their

prey that got eliminated after polluted water contamination. In this way, the whole ecosystem got affected after disturbance in single food chain organisms.

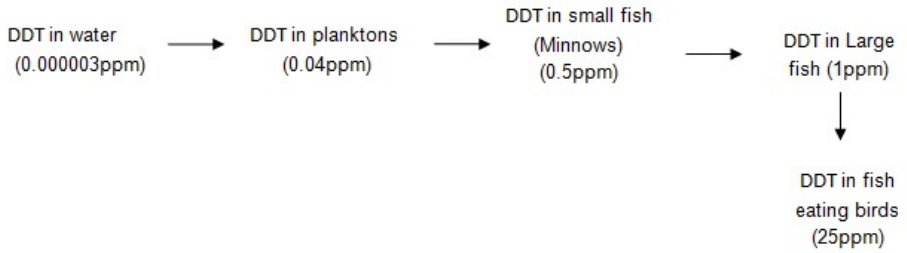
B) Eutrophication

Excessive addition of nutrients in the water bodies may lead to elimination of aquatic biota from the aquatic ecosystem through a process called Eutrophication. It is the process of enrichment of water body by means of consistent addition of nutrients dissolved waste water coming from agricultural runoff or other industrial effluents flow down into the water body. The dissolved nutrients might be phosphates, nitrates released from fertilizers, pesticides, etc. and other organic matter. These nutrients finds ability to stimulate algal growth on the surface of water that lead to algal nuisances and form an algal mat or cover on the entire water surface. The growing algae utilize available or dissolved oxygen at night for metabolic activities and may lead to de-oxygenation of water enough to the living organisms flourishing in the aquatic ecosystem. The algal mat formed over the water surface may block sunlight that brings photosynthesis of submerged plants or primary productivity of ecosystem to an end. Consequently, the other organisms suffer from deprivation of oxygen as well as food unavailability. The exhaustion of oxygen results in the death of aerobic organisms but stimulates the blooming of anaerobic ones. Certain anaerobic organisms pollute the water by secreting toxins, for instance sulphides and ammonia. All these toxins cause harmful health effects on aquatic life as well as organisms outside the water including humans. After blooming over the water surface, algae may die and sink to the bottom and feed the oxygen consuming bacteria. Decomposition of algae releases foul odour gases such as hydrogen sulfphide and the resulting silt and decaying matter may accumulate and ultimately fill the so called water body. This stage of water body e.g. lake or pond is termed as cultural or accelerated eutrophication when it changes into a dry land with the aid of water pollution from manmade activities. But if this stage arrive naturally than it is termed as senescence.

C) Bio-magnification

The concentration of several toxic substances like pesticides, insecticides and many other non-biodegradable increases as they transferred to next trophic

level of food chain. This phenomenon of progressive increase in concentration of toxic chemicals in organisms of a food chain is termed as bio-magnification. Example: If a fat soluble, persistent insecticide named DDT is introduced to water ecosystem than it is first taken up or absorbed by singled celled phytoplanktons or zooplanktons living in water. These planktons are ingested by small fishes that subsequently eaten by large fishes and store DDT in their body fat. These large fishes get consumed by fish eating birds or ospreys that accumulate the insecticide in fatty tissues. The tissue concentrations increase substantially at each tropic level of the food chain. Such increase in concentration and accumulation of toxic chemical contributed by means of passing contaminants from organisms at low trophic level to organisms at higher trophic level through bio-magnification that proves lethal to all living organisms.



D) Turbidity enhancement

Runoff from a variety of sources including bare or treeless soils, agricultural fields, mining and construction sites etc. adds up too much quantity of sediments into water bodies that may suffocate the fish by clogging their gills through deposition of sediments and also can block sunlight penetration, preventing aquatic plants from doing undergoing photosynthesis and thus reducing primary productivity. This eventually will lead to elimination of aquatic biota.

6.3.2. Effects on water/aquatic life

Water bodies or aquatic ecosystems like ponds, rivers, lakes, oceans and many other receive a number of toxic contaminants such as chemicals, heavy metals, etc. from a variety of domestic, industrial or agricultural sources and pollute the waterways and subsequently cause toxic effects on aquatic life including

phytoplanktons, zooplanktons, nektons, benthos, diverse group of turtles, fishes, worms and other countless organisms thriving there. All these aquatic organisms whether plants or animals depend on water for their survival. Water is the prime source of respiratory oxygen, essential nutrients and living habitat for these organisms. But contamination of water may bring physical, chemical or biological change such as increase or decrease in pH, turbidity, temperature etc. that could leads to destruction of their habit by de-oxygenation by hot water, dropping photosynthesis of planktons because of turbidity and cause death or elimination of aquatic flora and fauna. Excess of nutrients addition might lead to dominance of organisms like algae that results depletion of dissolved oxygen and kill the aquatic organisms due to asphyxia or deprivation of oxygen. Heavy metal contamination such as mercury poisoning may also cause deadly effects on fishes like tuna, mackerel, sharks, clownfish and other marine animals.

6.3.3 Effects on human beings

Pollutants from their respective sources discharges off into the water bodies which may directly through drinking or indirectly through food chain consumed by human being and impose their deleterious impact on human health. Besides health impacts human being also suffer from availability of pure, fresh drinking water with the pace of increasing water pollution day by day. There are a huge number of health effects of water pollution on human beings. Some of them have been enlisted below in table 1 which are caused by chemical pollutants while in table 2 enlisted those caused by pathogenic microbes.

Table 1: Health impacts of water polluting chemicals on human beings

Chemical Poisoning	Alias	Sources of causative agents	Severity / health impacts/Symptoms
Arsenic poisoning	Black foot diseases	tanneries, ceramic industry, effluents from fertilizers and insecticides industry,	diarrhea, peripheral neuritis, skin cancer, bladder and lung cancers
Cadmium poisoning	Itai-itai/ouch-ouch	Mining, smelting, phosphate fertilizers, sewage sludge, NiCd batteries, pigments, plastics,	renal disease nephritis and nephrosis aching illness of bones and joints, liver and

			lung cancers
Mercury poisoning	Minamata disease	Smelting industries, manufacturing of batteries, thermo-meters, pesticides, fungicides	diarrhea, impairment of senses, hemolysis, meningitis and even death also
Nitrate poisoning	blue-baby syndrome or methaemoglobi-nemia	Fertilizers, animal wastes,municipal and industrial waste water, refuse dumps,	impairs oxygen supply, proves lethal for infants
Fluoride poisoning (>1.5 mg/l)	fluorosis	**Natural:** Weathering of rock bearing minerals like apatite, fluorite, biotite and hornblend. **Anthropogenic:** Phosphate fertilizers, coal combustion, aluminium smelting, cement production, ceramic firing	Dental problems and dysfunctioning of respiratory, neuromuscular, gastrointestinal systems.
Lead poisoning	Lead poisoning	pipes, fitting, solder, household plumbing systems	Affects blood, CNS & kidneys dysfunctioning.

Table 2: Health impacts of microbial water pollutants on human beings

Water borne disease	**Causative organism**	**Health impacts/Symptoms**
Dysentery	Bacteria (Shigella dysenteriae)	Vomiting of blood, feces with blood/mucus,
Cholera	Bacteria (Vibrio cholera)	diarrhea, vomiting, fever, and abdominal cramps
Typhoid fever	Bacteria (*Salmonella typhi*)	prolonged episodes of fever, loss of appetite, nausea, headache, constipation, and loss of body weight
Amoebiasis	Protozoa (*Entamoeba histolytica)*	Affects intestine, symptoms include abdominal cramps and watery stools
Hepatitis A	Virus (Hepatitis	fever, nausea, vomiting,

	A virus)	
E.coli infection	Bacteria (Escherichia coli)	Diarrhea, dehydration,
SARS(Severe Acute Respiratory Syndrome)	Virus (Coronavirus)	Fever, lethargy, myalgia, sore throat, cough,
Botulism	Bacteria (*Clostridium botulinum*)	Vomiting, diarrhea, speech, dry mouth, blurred/double vision, difficulty in swallowing, breathing, muscle weakness,
Giardiasis	Protozoa (Giardia lamblia)	Abdominal discomfort, stomache, bloating, diarrhea, flatulence

Check your progress: Self-Assessment Questions (SAQ)

Q1. Which of the following is a not an anthropogenic source of water pollutant?

A) Oil spills B) Heat C) Sewage D) Rock weathering.

Q2. Sources that directly discharge their pollutants into water bodies from defined /identifiable source through pipes are called diffused sources. (True/False)

Q3. The phenomenon of progressive increase in concentration of toxic substances in organisms of a food chain is termed as _____.(bioaccumulation/bio-magnification)

Q4. Blue baby syndrome caused by poisoning of _____.

A) Arsenic B) Cadmium C) Nitrate D) Mercury.

Q5. Permissible limits for fluoride in water is _____.

Q6. Enrichment of water body by excessive addition of nutrients accelerates growth of which organism? A) Phytoplanktons B) Algae C) Zooplanktons D) Fishes.

6.4. Control measures of water pollution

Water pollution poses a serious threat on health of aquatic ecosystem, plants, animals and human beings. To control or minimize its devastating effects, required preventive measures should be checked, few of them are given below:

- Garbage disposal into water bodies should be avoided, instead should be dumped in compost pits to form compost.
- Minimize the use of detergents and bleach for washing clothes or dishes. Phosphate free soaps and detergents should be used.
- Overuse of fertilizers and pesticides should be minimized and not be disposed of into sewer systems.
- Washing cloths and bathing activities directly in the ponds, streams and other water bodies that make drinking water available should be prohibited.
- Sewage (domestic, municipal, farmyard) and industrial waste should be appropriately treated before sending them into their ultimate sink i.e. water bodies.
- Hot water from industries, power plants, should be cooled properly before releasing into water.

6.4.1. Sewage water treatment

Sewage, municipal and domestic waste waters should be treated properly to clean and free from any toxicity before pouring down into water ways. The treatment of sewage or waste water involves four stages: Preliminary treatment, primary treatment, secondary treatment and tertiary or advanced treatment.

A) Preliminary treatment

It involves removal of impurities that are suspended in water as coarse matter and the grit that floats on the surface of waste water through screening and skimming respectively. Screening eliminates papers, wood pieces, sticks, rags, polythene items, etc, while skimming eliminates impurities like oil, grease, etc. that are lighter than water. Some foaming or activating agents like Potassium xanthate are also used to enhance skimming process. After elimination of some removable impurities, the resultant water transferred into primary sedimentation tank as represented in fig. 2 where further treatment proceeds.

B) Primary treatment

This stage of water purification involves the settling of colloidal impurities, that are to fine to be screened out and too heavy to be skimmed off, as sludge and clear water remains above the sludge in the primary sedimentation tank. Sedimentation and flocculation or chemical precipitation techniques used for settling of these impurities. Settlement rate can be enhanced by adding some flocculating agents like potassium aluminum sulfate (potash alum), ferric chloride, etc. After primary treatment, the resultant clean water sends forfurther secondary treatment.

C) Secondary treatment

After primary treatment sewage undergoes secondary treatment that involves the digestion or decomposition of organic matter present in the water. This treatment can be done in two ways:

1) Aerobic secondary treatment: It takes place on aerobic conditions or makes use of oxygen. This kind of treatment can be done in two ways:

i) Trickling filter method

ii) Activated sludge method

i) Trickling filter method

In this method, sewage is made to pass through a thick layer of small stones or a bed of gravel laden with nutrients/culture media for bacterial growth. Bacteria present in the bed form small biofillms on the rocky surface and consume the organic matter present in the waste water/sewage during its filtration. The filtered or cleaner water free of any organic matter trickles out through the bottom of the bed and further propel for advance treatment to disinfect it or make it fit for drinking and other purposes.

ii) Activated sludge method

This method makes use of aeration technique along with microbial (bacteria and algae) action. An aeration tank and a settling tank are used in it. Aeration tank is provided with air while settling tank is provided with activated sludge at bottom containing bacteria and algae. Activated sludge from the settling tank passes into aeration tank where the sewage to be treated is also pumped

in. Mixing of sewage with air and sludge containing bacteria and algae takes place in the aeration tank where algae produces oxygen for bacteria and bacteria consumes organic matter present in waste water/sewage. Afterward, the components from aeration tank are shifted to settling tank from where the clear effluent free from organic matter is eliminated from upper side of the tank and promoted for tertiary treatment to completely purify while the activated sludge produced settles down at the bottom which is shifted to sludge digestion tanks for sludge treatment and disposal as shown in fig. 2.

2) Anaerobic or anoxic secondary water treatment: It makes use of a number of bacterial species to carry a series of digestion and fermentation reactions inside the large enclosed tanks called bioreactors or sludge digesters. These bioreactors consist of an inlet for sludge and four other outlets for removal of gas, scum, supernatant and sludge. After sludge digestion in bioreactor the resultant supernatant eliminated from an upper outlet and sent for again primary treatment as illustrated in fig.2 whereas the sludge settled down at the floor remove from outlet at bottom and sent for sludge treatment and the rest products are removed off.

D) Tertiary/advanced treatment

This stage serves as the final stage of water purification which encompasses a set of techniques that eliminate the remained soluble inorganic and microbial impurities stayed behind even after passing previous three stages of treatment. The techniques are:

Chlorination: Addition of chlorine or compounds containing activated chlorine like bleaching powder, NaOCl, etc. to disinfect water from pathogenic bacteria. Also for elimination of foul odours associated with hydrogen sulfide and other compounds produced during anaerobic digestion of organic matter.

Wet oxidation: It involves the oxidation of impurities, present in water after third stage of water purification, into harmless substances by using a suitable oxidizing agent such as hydrogen peroxides.

Adsorption: There are a number of compounds, that are not able to undergo biodegradation but have toxic effect, remain intact with water even after above

three stages of treatment. These type of compounds may be eliminated from water by passing them over a bed of granulated, activated charcoal. Charcoal adsorbs these kind of compounds and eliminate them from water. After the charcoal becomes saturated with these impurities, it is heated in vacuum to about 1800K and the impurities adsorbed on it driven off and the charcoal again become free and ready to reuse.

There are other techniques available also for water purification after secondary treatment namely Reverse Osmosis, electro dialysis, ion exchange, fluoridation, etc.

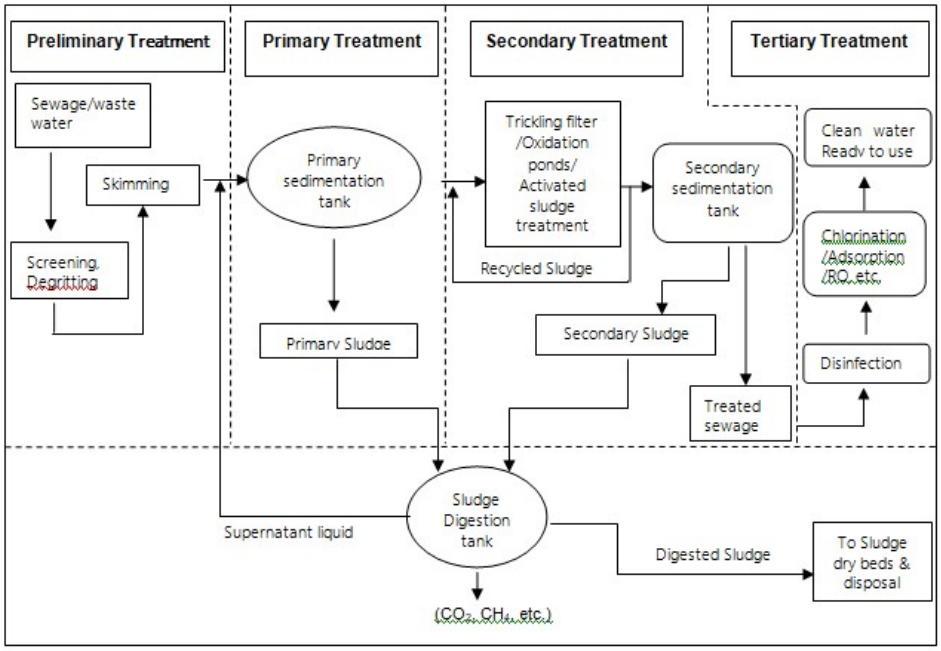


Figure 2: Overview of different stages involved in Sewage/Waste water treatment.

6.4.2. Industrial waste water treatment

Industries should be made legally bound in order to prevent discharge of untreated waste effluents to control menace of water pollution. There are some industries that generate normal domestic sewage that can be treated by municipal waste treatment plants while other industrial units that produce effluents with high concentrations of conventional pollutants like oil and grease, toxic substances like heavy metals, volatile organic compounds or other non-conventional pollutants like ammonia, require specialized/advanced

pre treatment systems. In industries, where required, pre treatment systems should be installed to eliminate harmful contaminants neutralization of acids and alkalies, elimination of toxic substances via chemical oxidation, coagulation of colloidal impurities, metallic compounds precipitation, cooling of waste water, etc. Then, the resultant partially treated wastewater should be send to sewage/municipal waste water treatment system (as discussed in 1.5.1) for further purification.

6.4.3 Agricultural waste water treatment

Washed off sediments (loose soil) and nutrients runoffs from agricultural fields are the prime source of agricultural pollution. These kinds of runoff flows can be controlled by adopting erosion control strategies which are also useful in retaining valuable soil within the fields. As per Environment Protection Act 2003, the major strategies for erosion control consists of crop rotation, crop mulching, cultivating perennial crops, contour plowing, installing riparian buffers and many more. Nutrients such as nitrogen and phosphorus form a major component of agricultural runoff, which introduced into the soil by application of synthetic fertilizers to farmland, animal dung, or treating the fields with sludge generated at municipal or industrial effluents treatment. Crops absorb the required nutrients from soil and the remaining surplus residue forms a part of runoff flows, irrigation water and atmospheric deposition. To control agricultural pollution proper management plan for removal of excess nutrients from the fields are required to be developed and implemented strictly. Overuse of chemical pesticides and fertilizers should be minimized. To decrease dependency on chemical pesticides and to control water contamination, biological approaches for pest control such as integrated pest management should be encouraged instead of application of toxic chemical pesticides.

6.4.4 Thermal water pollution treatment

There are mainly three methods to control thermal pollution: cooling ponds, spray towers and cooling towers.

A) Cooling Ponds

This method incorporates water bodies like ponds and rivers to cool down the hot water in order to prevent thermal pollution. Hot water from condensers of factories, industries or any source is transferred into ponds and stored for sometime where natural evaporation results cooling of hot water by dissipating heat and the cool water then discharged in the nearby water body as shown in fig. 3.

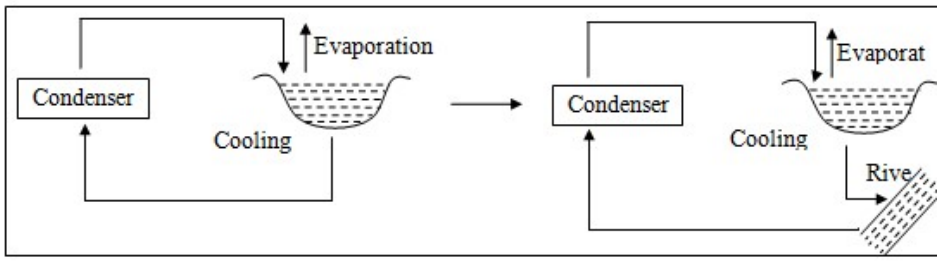


Figure 3: Dissipation of heat through cooling ponds

B) Spray towers

It involves the use of pond like structures called spray ponds which receives the hot water from condensers by spraying in the form of fine jets through spray nozzles attached with the spray towers. The sprayed water dissipates its heat into the atmosphere and the cool water from spray towers recirculated into the nearby water body as shown in fig.4.

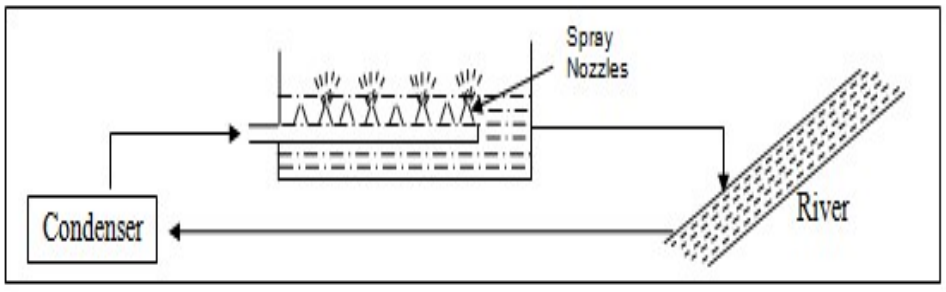


Figure 4: Dissipation of heat through spray towers

C) Cooling towers

These include wet and dry cooling towers (fig. 5) described below:

1) Wet cooling towers

In this method, hot water enters into an open system/tower through the inlet and sprayed over the baffles. The hot water inside the tower comes in contact

with cool air entering from sides and loses its heat. The resultant warm air and steam lost through evaporation forming fog over the wet cooling tower and the cool water is recycled or discharged in the nearby water body.

2) Dry cooling tower

This method involves a closed system of pipes having two openings i.e. inlet and outlet. From the inlet hot water enters into the tower where cool air from fans comes in contact with hot water and resulting dissipation of heat. In this way, hot water gets cooled and only warm air goes out through the tower. The cool water then discharged off into the water body.

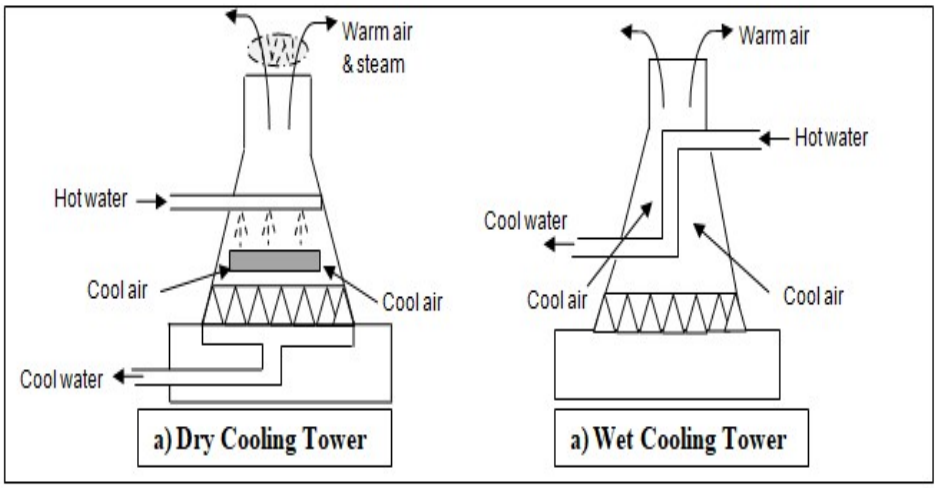


Figure 5: Dissipation of heat through a) Dry Cooling Tower and b) Wet Cooling Tower

6.5. Summary

In this chapter, we have studied about the different aspects of water pollution, its effects and control. Let us recall so far what we have understood.

- Water pollution is the condition when introduction of any foreign substance into water makes it unsafe to drink, unfit for usage, impose toxic effects which results due to change in its physical, chemical or biological characteristics.
- Water polluting agents commonly known as water pollutants might be any organic compound, inorganic molecule, pathogenic microorganisms, thermal heat, radioactive substances, sediment/suspended matter and many more.

- Contamination of water on surface or land refer to inland/surface water pollution, in seas and oceans called marine pollution while pollution due to introduction of heat into water leads to thermal pollution and pollution due to infiltration of contaminants through soil into ground water with rainwater flow results groundwater pollution.
- Water pollution has deleterious effect on water/aquatic ecosystem, aquatic life and human health. Contamination of toxic substance into water bodies leads to nutrient pollution commonly called eutrophication that can completely destroy the aquatic ecosystem by converting the water body into dry land.
- Toxicity of contaminants may change water quality abruptly that could badly affect the health of aquatic organisms inhabiting water body. Introduction of heat may kill organisms flourishing under water as the hot water causes de-oxygenation of water body.
- Human beings, either directly through drinking polluted water or indirectly through consumption of fish like aquatic organisms living in contaminated water, suffer from the effects of water pollution. Human health may get damaging effects by acquiring inorganic chemical poisoning such as arsenic poisoning, lead poisoning, mercury poisoning, etc. and water borne disease like cholera, dysentery, SARS, etc. that might have caused death also.
- Different type of pollutants generated at their source including industries, domestic and municipal sewage should be eliminated or freed from waste water or effluents before discharged of into water bodies.
- Sewage from various sources should be treated in sewage treatment plant, industrial waste should be purified in specialized effluent treatment plants, agricultural pollution should be controlled by adopting proper management plan and integrated pest management and different cooling techniques such as cooling ponds, spray towers and cooling towers should be incorporated for thermal pollution water control.

6.6. Glossary

Aquatic ecosystem	Communities of living organisms like aquatic plants and animals inhabiting water bodies form a living environment called Aquatic ecosystem.
Bioaccumulation:	Building up of toxic chemicals within the tissues and organs of the body of an organism.
Bio-magnification:	Progressive increase in concentration of toxic chemicals in organisms at different trophic levels of a food chain is termed as bio-magnification.
Eutrophication:	Addition of nutrients like nitrogen and phosphorus rich runoff into water body resulting accelerated growth of algae over the surface of water
Fertilizers:	Chemicals sprinkled over crops for growth enhancement
Food chain:	Linear sequence of organisms linked together for food where an organism becomes food for organism at next trophic level
Pathogen	Disease causing organism
Sewage:	Type of wastewater that is produced by a community of people and excrement conveyed in sewers.
Storm water :	Water from floods
Water pollution:	Alterations in the water characteristics by addition of harmful materials into the water.

Answer To Check Your Progress/Possible Answers To Saq

1. (D)
2. False
3. Biomagnification
4. (C)
5. <1.5mg/l
6. (B)

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Terminal and Model Questions

Q1. Describe briefly about different types of water pollution.

Q2. How does water pollution affect human health?

Q3. Explain the process of transforming water body into dry land through eutrophication.

Q4. Describe the mechanism of sewage water treatment.

Q5. How industrial waste water treatments differ from sewage or municipal waste water treatment?

Q6. Differentiate between dry and wet cooling towers for thermal water pollution control.

Unit 7: Soil Pollution

Unit Structure

7.0. Learning objectives

After reading this unit you will be able to:

- Understand what is soil pollution and how does it occur?
- Comprehend nature of soil pollutants
- Differentiate between point and diffused sources
- Differentiate between natural and anthropogenic sources of soil pollution

7.1. Introduction

Soil is a thin, loose and porous layer consisting of organic and inorganic materialsin the earth`s upper crust. It is defined as "the unconsolidated mineral or organic material on the immediate surface of the earth that serves as a natural medium for the growth of land plants". Soils vary greatly in physical and chemical properties and to assess the soil condition one should examine the physical characteristics of soil carefully. These physical characteristics include texture, color, depth, structure, porosity etc. The combination of mineral part (gravel, sand, silt and clay particles) and organic matter part give soil its texture. The color of the soil indicates its organic content and how well is it drained, if the soil is poorly drained, sufficient oxygen cannot reach to the plant roots resulting the stunting or death of the plant. The soil components

can be classified into two categories: abiotic and biotic. The abiotic part of the soil includes the organic matter, inorganic matter, liquids (majorly water), gases and different sized mineral particles (clay, silt and sand). On the other hand, the biotic component of the soil includes a consortium of microorganisms (bacteria and fungi), animals and plants. Thus, soil has a direct influence on water and atmospheric quality, and consequently, on human and animal health. It performs several ecosystem services (key functions) which can be classified into four general categories: productivity and sustainability, environmental quality, biodiversity, and human wellbeing. Being a major resource, soil is often misused which has led to the depletion of soil and its vitality, leading to the degradation of soil and causing soil pollution.

The investigation of the current unit will help to peruse in building up a comprehension of the basics of soil contamination. It will likewise give the thought regarding various kinds of soil contaminations: its type, nature and fate.

7.2. Soil Pollution

Soil pollution can be defined as the intentional or accidental introduction of foreign compounds or chemicals that react and change the soil composition leading to gradual depletion or prolong toxicity causing health hazard and bio-magnification in humans, animals and plants. The major cause of soil pollution is directly linked to anthropogenic activities such as deforestation, dumping of waste, use of excessive pesticides, fungicides, fertilizers leading to increase salinity, loss of fertility, low mineral content etc. The harmful effects of soil pollution may come from direct contact with polluted soil or from contact with other resources, such as water or food which has been grown on or come in direct contact with the polluted soil. Many soil pollutants are carcinogenic in nature, and if exposed to such pollutants may increase the risk of cancer in humans for example polychlorinated biphenyls (PCBs) are known to cause liver cancer.

Soil pollution can also cause neuromuscular blockage as well as depression of the central nervous system, headaches, nausea, fatigue, eye irritation and skin

rash. Soil does not need to be highly contaminated to be harmful to humans and the soil that are not significantly polluted may still harm humans directly though bioaccumulation, which according to Pollution Issues, occurs when plants are grown in lightly polluted soil, which continuously absorb molecules of the pollutants (Everythingconnects.org.,2013)

7.3. Types of Soil Pollution

Soil pollution can be categorized as either a point source or a diffuse source, depending on where the pollutants come from. Soil pollution can be categorized as natural or anthropogenic depending on the source. The detailed discussion of above classification is given below.

1. **Point source soil pollution**

The soil pollution occurring from a specific area or event is said to be a point source, it can be easily identified and the main cause of such pollution is often anthropogenic activities such as spills of pesticides/ oil, excessive use of chemical fertilizers, dumping of untreated waste or sewage, mining activities etc. point source pollution is often found common in urban areas.

2. **Diffuse source soil pollution**

The pollution that occurs far from the original site via air or water routes is termed as diffused source of soil pollution. Its examples may include soil erosion, flood events, surface runoff, atmospheric transport via wind etc. This pollution doesn't provide the exact location of its source since most of the deposition occurs associated with some other events.

7.4. Sources of Soil Pollution

Soil pollution is caused by the presence of man-made chemicals or natural alteration of soil in the environment. Generally, soil contamination comes from rupture of underground storage links, volcanic eruption, excessive rainfall causing subsurface run-off, application of pesticides, improper disposal of industrial waste, etc.

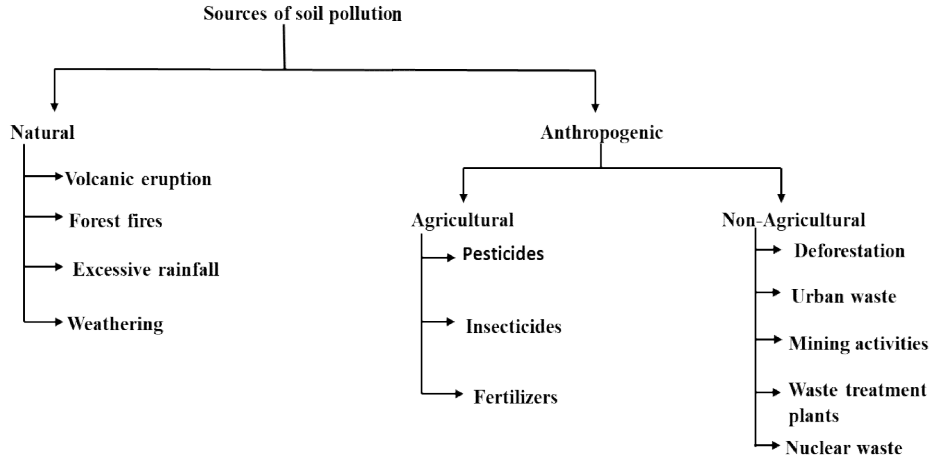

Figure- 1: Sources of soil pollution

7.4.1. Natural pollution

The natural sources of soil pollution may include weathering of rocks, soil erosion, earthquake, landslide, flood, and hurricane such events can lead to the removal of top fertile layer of the soil causing the excessive addition of chemicals, salts, heavy metals, radioactive substances etc. Besides from it, certain soil parent materials are prominent sources of heavy metals and radio nuclides that, at high concentrations, can be harmful to the environment and human health. One such example is arsenic pollution. Volcanic eruptions and the weathering of As-containing minerals and ores are major natural sources of As(Wuana & Okieimen, 2011). Elevated level of arsenic in drinking water is responsible for Black-foot disease also known as Arsenicosis. Similarly, natural events like volcanic eruptions and forest fires also result in soil pollution by releasing hazardous substances such as heavy metals and polycyclic aromatic hydrocarbons (PAHs) into the surroundings. Although such threats are beyond the human control, appropriate strategies should be established to reduce the impact of such hazards on the soil profile.

7.4.2. Anthropogenic source of soil pollution

The Anthropogenic sources as the name suggests is the man-made therefore such source of pollution includes the impacts of human based activities which include improper waste disposal in landfills, excessive use of pesticides, herbicides, insecticides, excessive use of fertilizers like NPK, improper

disposal/ dumping of industrial effluents directly to the soil leading the earth susceptible to heavy metals, toxic chemicals, radioactive substances etc.

7.5. Major Soil pollutants

Pollutants are the chemical or substance out of place and/or present at higher-than-normal concentration that has adverse effect on any non-targeted organism (Pollution et al., n.d.). In case of soil, these pollutants could be heavy metals, poly-aromatic hydrocarbons, petrochemical substances, agrochemicals (such as pesticides, insecticides, herbicides etc.), radioactive substances etc. They may cause long- or short-term damage by changing the growth rate of plant or animal species, by interfering with environmental good health or interfering with human, comfort, health, or property values.The following are some of the most common soil pollutions.

Heavy Metals- The elements having density less than 5 g $m^{-3}$and atomic number greater than 20 are categorized as heavy metal. They are also called trace elements as they constitute < 1% of the rocks present in earth curst (Wuana & Okieimen, 2011).Cu, Pb, As, Zn, Cd, Hg, Cr, and Ni are the most common heavy metals found in soil.Though they are naturally found in rocks and sediments, their concentration is increasing with the increase in human activities. As a result, most soils in rural and suburban areas have heavy metal buildup above stated background values, posing a risk to human health, plants, animals, and ecosystems(Harission, R.M, 2007). Rapid expansion in industrial area, mines trailing, excessive application of pesticides, fertilizers, coal combustion residues, sewage sludge, atmospheric depositions etc., are the major responsible cause for heavy metal pollution in soil. The magnitude of metals' impacts on biological and biochemical qualities is influenced by soil properties such as organic matter, clay concentration, and pH. E.g., decrease in pH, increases the mobility of heavy metal within the soil. These metals have detrimental effect on soil biota, as they interfere with the essential microbial processes further reducing the number an activity of soil micro-organism. Further, heavy metal uptake by plants and subsequent accumulation along the food chain pose a serious threat to animal and human health.

Agrochemicals-The term agrochemical is often used as a generic term for the chemical products or pesticides used in agriculture. Depending upon the target species they are categorized as herbicides, weedicides, insecticides, fungicides etc., along with the synthetic fertilizers and soil conditioning agents. Agrochemicals are used extensively in modern agriculture to improve crop output by reducing damaging pests, diseases, and unwanted weeds(Meena et al., 2020).As a result, the soil receives the majority of complex agrochemical compounds, many of which are toxic to non-target beneficial soil microorganisms involved in nutrient cycling and biotransformation processes. About 80-90% of pesticides that are sprayed to crops can directly harm non-target vegetation, or they can drift or volatilize from the treated region and pollute air, soil, and non-target plants (Sun et al., 2018). Apart from it, these chemicals pose a huge risk to human beings indirectly, via food chain and contamination of natural resources. These chemicals are responsible for different acute (stinging eyes, rashes, blisters, blindness, nausea, dizziness, diarrhea) and chronic health effects (cancers, birth defects, reproductive harm, immune toxicity, neurological and developmental toxicity, disruption of the endocrine system).

Industrial waste-It mainly include waste discharged from various origins such as pulp and paper mills, chemical fertilizer, tanneries, textiles, steel, distilleries, cement, petroleum industries etc. (Bowen, 1975). Untreated waste from industries can contain a variety of metals, chemicals, salts, and radioactive elements.They either reach the soil directly through water or indirectly through the air (wet/dry deposition).These chemicals accumulate in soil and have a negative impact on plant growth and human health.

Urban waste-It includes commercial and domestic wastes, such as dried sludge and sewage, garbage and rubbish materials e.g., Plastics, glasses, metallic cans, fibers, paper, rubbers, street sweepings, fuel residues, leaves, containers, abandoned vehicles. The nutritional content of sewage treatment plant waste, particularly N and P, has a beneficial influence on soil health. However, its significance is reduced by the presence of potentially harmful content, such as polychlorinated biphenyls (PCBs), polychlorinated triphenyls

(PCTs), poly aromatic hydrocarbons (PAHs), aromatic amines etc. (Harission, R.M, 2007)

Pathogens- Pathogens are microbes that cause diseases. Despite the fact that soil biodiversity is extremely complex, comprising zillions of bacteria, fungus, protists, and animals, not all microbes are beneficial, and some are disease-causing.Pathogenic microorganisms can be found in soil from a variety of sources, including the burial of animal and human remains, manures, and sewage sludge.Some pathogens may originate from animal excreta.Thus, soil becomes primary source of contamination through dermal contact or contact with contaminated water and food. The following is a list of some common soil-borne diseases along with their causal micro-organism.

Table 1- Common soil born diseases with their respective causal organism(Bowen, 1975)

Disease	Pathogen
Anthrax	*Bacillus anthracis*
Giardiasis	*Giardia lamblia*
Salmonellosis	*Salmonella enterica*
Ascariasis	*Ascariasis lumbricoides*
Gas gangrene	*Clostridium perferingens*
Botulism	*Clostridium botulinum*
Trichenellosis	*Trichinella spiralis*
Mucromycosis	*Rhizopus sp.*
Q fever	*Coxiella burnetti*
Actinomycetoma	*Actinomyces israelli*

7.6. Summary

In this unit you have studied that-

a) Soil pollution is the contamination of soil by human and natural activities which may cause harmful effect on living organisms. These

may vary from short to prolong effects depending on the type and origin of the soil pollutants.

b) Depending on the site, the nature of the pollutant is decided, which leads to the classification of soil pollutants as point source pollutants and diffuse source pollutants.

c) Although the soil is polluted by both natural and anthropogenic activities, still the dominant source of pollution is the man-made which includes agricultural practices, urban settlements, industrial development, waste disposal, military activities etc.

d) The major pollutants that play key role in the depletion of soil maxima are heavy metals like As, Cu, Pb, Cd etc., pesticides such as DDT, DDE, Aldrin etc., PAHs and POPs play the most crucial role in form of xenobiotics and carcinogens leading to bioaccumulation and intrusion of such chemicals in food chain over prolong years and cycle.

e) Soil hosts variety of microorganism out which some possess disease causing ability. These organisms are called Pathogens. A large number of acute and chronic diseases are caused by them.

TERMINAL QUESTIONS

1. Define soil pollution and its causes.
2. Explain point and diffuse source of soil pollution.
3. What are the natural and anthropogenic sources of soil pollution? Explain and discuss in brief.
4. Describe the heavy metal present in the soil.
5. Discusses the soil borne diseases along with their causal organism.

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Unit 8: Impact and Control of soil Pollution

Unit Structure

8.0. Learning objectives

The investigation of the current unit will help the perusers in building up a comprehension about the impact of different soil pollutants. It will likewise give the thought regarding various kinds of remediation technologies: their principle and applicability required to mitigate soil pollution.

After reading this you will be able to:

- Understand the impacts of soil pollutant.
- Select suitable remedial measures to comate soil pollution.
- Differentiate between soil remediation technologies
- Understand sustainable soil management practices.

8.1. Introduction

Soil is by far the most biologically diverse ecosystem on Earth and has been evolved in nature to perform several ecosystem services critical for life such as filtration of water, acts as medium and nutrient reserve for plant growth, provides habitat for billions of micro- and macro-organisms contributing to biodiversity etc. Thus, itis an "all-inclusive sink" that bears the best weight of natural as well as anthropogenic contaminations. However, with the

advancement of the present-day civilization, humans have started using land as a dumping site for solid waste, establishing urban communities and towns. The unmanaged anthropogenic activities such as excessive application of chemical fertilizers and pesticides, deforestations, excessive industrial activity, inefficient waste disposal etc have created pressure on soil sustainability. All the aforementioned causes can lead to serious health conditions at all the level of ecosystem. Plants that grow on contaminated soil may have lower yields, because the hazardous chemical in soil meddles with their growth. Animals that eat polluted soil particles or contaminated plants may also grow slowly or succumb to diseases and /or death. In addition, human health is also impacted significantly due to contaminations and deterioration in the soil quality. To deliver issues identified with soil contamination, several nations, including India, have defined activity plan and methodologies to recognize and battle soil contamination with the end goal of securing the sustainability of soil and its properties. The current chapter sums up the unsafe effects of soil contamination on soil biota further followed by its remediation techniques.

8.2. Impact of Soil Pollutants on Soil Biota / Microbes

The functioning of soil as a vital system and its biological productivity is directly related to its micro-floral activities. Soil provides habitats for a vast, complex and interactive community of micro-organisms whose activities largely determine the fate, chemical and physical properties of the soil. A hand full of soil supports zillions of microbes at a time. Microbes actively participate in the regulation of biogeochemical cycles such as carbon, nitrogen, phosphorous, Sulphur etc. On the other hand, soil constantly receives huge amounts of agrochemical every year. Many of them are noxious for non-targeted beneficial soil micro-organism. All these chemicals are highly persistence in nature hence they tend to remain in soil for very long duration. Apart from this, the susceptibility of microbes towards the chemicals also depends upon its bioavailability, adsorption, absorption, texture of the soil, organic content etc. Though, the microbes are active destructors of pollutants, sometimes they themselves get affected by pollutants. The latter can destroy whole community of pollutants by altering their metabolism. If microbial

population gets affected by soil contaminations, their nutrient cycling will be lost and thus soil became infertile/toxic too. The alteration in diversity and composition of the beneficial microbial community can be unfavourable to plant growth and development either by reducing nutrient availability or by increasing disease incidence.

Table: 1 Impacts of agrochemicals on soil microbes and associated processes(Meena et al., 2020).

Agrochemical	Example	Effects on microbes
Herbicides	2,4-D	Reduces nitrogenase, phosphatase, and hydrogen production activities of purple non-sulphur bacteria
	Bentazone, Promtryn, Simazine, and Terbutryn	Inhibit N-fixation and decreases the nodules and N content overall
	Glyphosate	Supress phosphate activity
Fungicides	Benomyl	Impacts mycorrhizal associations and nitrifying bacteria
	Dinocap	Inhibits the activity of ammonifying bacteria
	Mancozeb	Impacts bacteria involved in N cycling
	Captan, Carboxin, Thiram	Inhibits the activity of bacteria responsible for denitrification
Insecticides	DDT, lindane	Decreases the bacterial biomass
	Chlorinated, Hydrocarbons	Inhibits methanogenesis
	Chlorpyrifos, Quinalphos	Reduces ammonification process.
	Neemix-4E	Reduces urease enzyme activity
	Pentachlorophenol	Reduces nitrification

8.3. Effects of Soil Pollutants on Vegetation

In recent year due to increased industrialization, unplanned urbanization and unsustainable anthropogenic activities it soils gets polluted by various kinds of pollutants like heavy metals (Pb, Cu, Cd, Hg, As & Al), PAHs, POPs, radio nuclides (^{137}Cs, ^{238}U) and micro pollutants (micro plastics, pharmaceuticals & antibiotics) which is harmful for any kind of vegetation. Heavy metals like Cd

and As are responsible for decreased photosynthetic rate, toxicity of mercury reduces the transpiration rate, root elongation and chlorophyll synthesis. Heavy metal Cu and Al causes chlorosis of leaves and change in ultra structure of roots respectively. Polyromantic hydrocarbons (PAHs) like anthracene, naphthalene and pyrene inhibits the photosynthetic performance, loss of pigment and change in protein composition. Persistent organic pollutants (POPs) like pesticides are toxic for plant due to its persistent nature it causes necrosis, chlorosis, stunting, burns and twisting of leaves in plants, poor root hair development and yellowing of shoot. Radionuclides like ^{137}Cs mimic K and replaces it and hinders the movement of nutrients and water in plants as well as plants physiological function of plant is affected due to accumulation of Cs in leaves. Micro plastics are toxic to plant roots and antibiotics like tetracycline inhibits the plant growth.

Table 1. Soil pollutants and their effects on vegetation

Soil pollutants	Effect on vegetation
Heavy metals	Decreases photosynthetic and transpiration rate
PAHs	Inhibits photosynthetic performances
POPs	Necrosis, chlorosis, stunting, burns and twisting of leaves in plants, poor root hair development and yellowing of shoot
Radionuclides	Affects the movement of water and nutrients
Micro pollutants	Toxic for root and inhibits plant growth

8.4. Control measures of soil pollution

The soil conservation measures include the "blend of practices" being able to fight soil pollution. Variety of such practices have been developed in the

previous few years, for example, soil washing, thermal desorption, bioventing, soil vapour extraction and so forth. Apart from this, distinctive feasible sustainable practices have likewise been utilized in different parts of the world. A portion of remedial measures have been discussed below.

8.4.1. Soil remediation technologies

Remediation technology involves physical, chemical, and biological techniques that are implemented either in situ or ex-situ after excavating the contaminated soil. The clean-up is usually achieved through extraction of contaminants from the site, transformation of a contaminant into a less toxic form or stabilization and solidification. Several remediation technologies have been developed in the past few years, aiming to restore the soil to its natural pollution free-state.

Selection of a remediation technology depends upon-

- Size and contaminated area and its topographical location.
- Source and route of contaminants.
- Physical and chemical property of the contaminants.
- Degree of pollution i.e., contaminants concentration and the distribution throughout the soil profile.
- Complements the legal and social issues of the region as well as country.
- Possible impact of remediation technology on environments.

In the present section, some commonly available remediation technologies and their appropriate applicable areas have been discussed.

8.4.2. Soil washing

Soil washing is an ex-situ remediation process. It removes the contaminants from the soil through physical separation, followed by chemical leaching via chemical solvent (Fernández Rodríguez et al., 2014). It relies on the principal that most organic and inorganic contaminants tend to bind with smaller soil particles. Thus, washing processes separate the smaller particles like clay and silt from coarse grained particles such as sand and gravel. It basically

concentrates the contaminants into the smaller volume of soil (sludge) which can be further treated using various other remediation technologies such as chemical oxidation, thermal desorption, bioremediation or can be disposed in a permitted landfill (Sharma and Reddy,2004). Finally the course grained fraction is sent back to excavated site. This method significantly reduces the initial volume of the contaminants present in soil, often making it a pre-treatment step in other remediation processes (US-EPA, 1993).

Soil washing techniques can be effectively applied to soil contaminated with different organic and inorganic contaminants such as volatile organic compound (VOCs), polychlorinated biphenyl (PCBs), pentachlorophenol (PCPs), heavy metals, radio nuclides, pesticides, petroleum and fuel residues etc (Geoengineering.org 2013). A key factor in determining the applicability of soil washing at a particular site is the grain size distribution of the soils requiring treatment. The lower the silt, clay, and organic material levels, the more effective soil washing will be (soils with higher hydraulic conductivities work best). Soil washing may not be applicable if the contaminants adsorb strongly onto the soil particles, Since, the washing process is not always able to fully remove the contaminants from the soil surface. This situation would require an additional remediation technique to fully clean the soil.

A schematic diagram of soil washing technology is shown in figure-1. The process begins with the excavation of contaminated soil further moving it to a staging area where, it is prepared for the treatment. After the initial treatments the soil undergoes the screening processes, it basically removes the large objects such as babbles, pebbles and debris. Once the screening is done, the remaining materials enter to the soil scrubbing unit, in which the soil is mixed with washing solution which removes the contaminants from the soil. Based on their grain size, the soil particles settle down in the wash water. Once their settlement is done, both the soil particles and the wash water are tested for contaminants. If they are found clean, they are sent back to site or reused further. But if any contaminant is present, they undergo further treatments(USEPA, 1996).

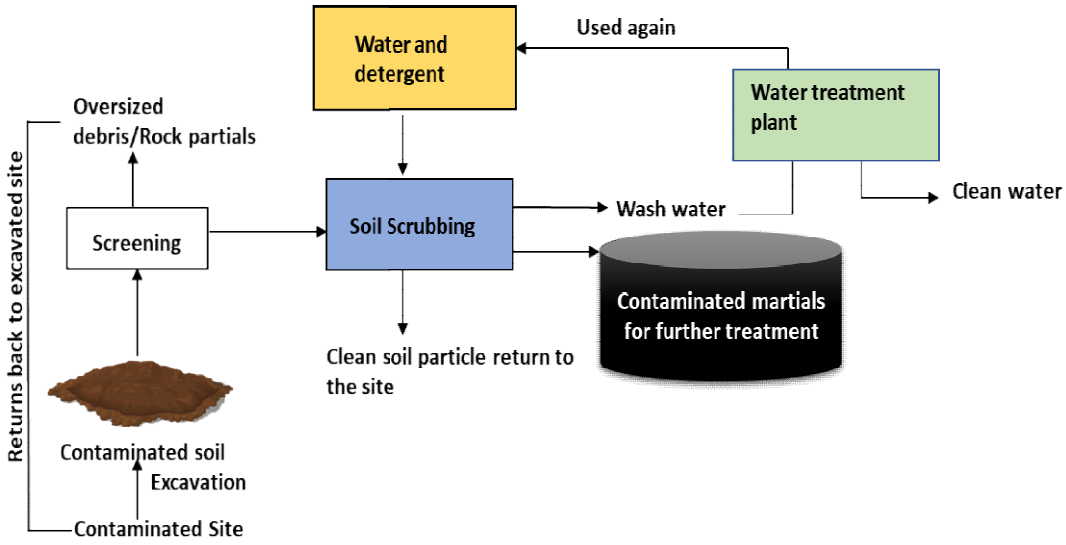

Figure-1 Schematic representation of soil washing technique.

Advantages –

There are several advantages associated using soil washing as a remediation technique. Some of them are listed below.

- The process significantly reduces the volume of contaminated soil in that the contaminates are concentrated in relatively small mass of material. When the process is performed in ideal condition, it can result in 90% reduction in the total volume.
- Potential removes both organic and inorganic contaminants.
- As it is performed in closed system it becomes easy to monitor and control soil parameters such as pH, temperature, moisture content etc.
- It is quite cost-effective compered to other remediation technology.
- Approximately, 70 tons of soil can be treated per hour.

8.4.3. Vitrification

In general, vitrification is the transformation of substance into a glass.It could be accomplished by rapidly cooling a material after it has been heated to a very high temperature (Geoengineer, 2013).Soil vitrification entails using heat

to melt contaminated soil and convert it to a glassy or crystalline product that prevents further leakage. Soil is heated upto temperature ranging 1600-2000ºC (2900-3000ºF)(Dutta, 1997). It's best for soils holding waste like hydroxide, carbonates, and silicates, incinerator ash or off-gas liquor, radioactive material, and chemical process waste.It is also particularly effective for organic waste, as high temperatures render organic waste inactive(Sharma and Reddy, (2004).It can be used as both an in-situ and an ex-situ technique.

In-situ vitrification (ISV)- It involve the application of electrical power to heat and melt soil, sludge or sediments. It employs a graphite-based electrode system with a 5 cm diameter that is put 60 metres into the ground and forms a square 1 metre edge(Siveris et al., 2019).An electric current is passed through the electrode, prompting the soil to become overheated; the molten material is subsequently cooled, forming a vitrified surface.The melting continues downward and outward at a rate of 4 to 6 tonnes per hour, or 1 to 2 inches per hour, as power is supplied. The electrode array is lowered progressively, as the melt grows toward the set treatment depth. A vitrified monolith with a glass and microcrystalline structure remains after cooling. This monolith is extremely strong to with stand weathering.

Ex-situ vitrification(ESV)- In specific reactors, ex-situ vitrification treats contaminated soil. In-situ vitrification is a related concept. The distinction is that prior to treatment, the waste must be excavated.The contaminated soil is placed into a furnace, which heats and vitrifies the soil. Heating devices include plasma torches and electric arch furnace. In plasma torch technology, waste soil is fed into a rolling furnace; here, the waste and the molten material are kept against the side by centrifugal forces. The waste moves through plasma, created by a fixed torch during rotation. The spinning of the hearth is slowed to remove the molten material from the furnace, and the slag exits via the bottom aperture. Similarly, arc furnace system includes, Carbon electrodes, cooled sidewalls, a continuous feed system, and an off-gas treatment system. Waste is fed into a chamber where it is heated to temperatures above 1500º C. Inorganics are immobilised as the melt exits the vitrification unit and cools to create a glassy solid.

Advantage-

- Waste glass product has stable chemical and physical properties making it resistance against weathering and leaching
- It is good option especially for the disposal of fly ash containing heavy metal, toxic chemicals and radioactive wastes.
- It's working efficiency is about 95-99.9%.

8.4.4. Gas based technologies

The basic principle behind these technologies relies on application of vapor/ air directly to the contaminated site. Soil surface extraction, bioventing, air

8.4.4.1. Soil vapour extraction

Soil vapor extraction (SVE) is a physical process used to remove chemicals from the soil's vadose zone of a subsurface environment. It is an efficient technology used for the remediation of soils contaminated from volatile or semi-volatile organic compounds located in the unsaturated zone of the soil such as petroleum range hydrocarbons (PROs), diesel range hydrocarbons (DROs), benzene, toluene, ethylbenzene, xylene etc.

Itis based the application of a vacuum to the soil, creating an airflow through the soil matrix that transports the contaminants to extraction wells and air treatment units before their release in the atmosphere (Greene & Pimie, 2003).Typically, SVE can be used to remediate contaminants based on Henry's Law constant >0.01 or vapour pressure > 0.5 mm Hg gas flow and airflow in the unsaturated zone,which is induced by creating a pressure gradient (Framework, 2018).

The cleaning process in SVE system is governed by 4 different processes which are as follows (Sharma and Reddy 2004)-

Volatilization-It is the predominant process within the soil vapour extraction system. The contaminants present on the surface of soil particles turn to vapor when soil air passes through it, which is then collected through extraction wells.

Advection- when vacuum is applied to the vadose zone, it creates pressure gradient within the zone. As a result of which the contaminants present in vadose zone starts moving towards the extraction well.

Diffusion- It is a process where a substance will spread out or "diffuse" into the surrounding area. Diffusion occurs due to a negative concentration gradient caused by the extraction wells, so the contaminants with the higher concentration will diffuse toward the wells where there is little to no concentration of contaminants.

Desorption-It is the removal process of the contaminants from the soil surface. When vacuum is applied to the system, the soil-air is removed from the surface of the soil and moves throughout the void spaces of the soil particles towards the extraction wells because of a concentration gradient within the soil.

Advantages-

- It is very easy to monitor, allowing the treatment time relatively short and inexpensive to implement
- It causes minimum disturbance to the site
- It is very easy to couple with other remediation techniques

8.4.4.2. Bioventing

Bioventing is an in-situ environmental remediation technique. It is based on bioremediation principle which involve soil microbes to degrades the toxic contaminants present in unsaturated zone of soil. This technique involves controlled stimulation of airflow by delivering oxygen to unsaturated (vadose) zone in order to increase bioremediation, by increasing activities of indigenous microbes (Rodríguez et al., 1989).

Bioventing systems are unique in that they are designed to not only volatilize gasoline compounds for removal, but also to biodegrade them in the field.Both bioventing and soil vapour extraction have identical instrumentation, but their principle vary significantly. Unlike bioventing that relies on enhancing microbial degradation process at the vadose zone by moderate air injection, soil vapour extraction (SVE) maximizes volatile organic compound volatilization via vapour extraction (Azubuike et al., 2016). All aerobically

biodegradable constituents can be treated by bioventing. In particular, bioventing has proven to be very effective in remediating releases of petroleum products including gasoline, jet fuels, kerosene, and diesel fuel.

Soil moisture content plays very important role in bioventing process. High soil moisture or low permeability of soil reduce bioventing performance. Low temperatures may slow remediation process. Along with this maintaining adequate air flow rates becomes very important. High airflow rate leads to transfer of volatile organic compounds to the soil vapour phase, which requires off-gas treatment of the resulting gases prior to release into the atmosphere (Azubuike et al., 2016)

Advantages-

- Requires short treatment times usually, 6 months to 2 years under optimal condition.
- Use readily available equipment and easy to install.
- Create minimal disturbance to the operational site and can be used to address inaccessible areas.

8.5. Sustainable soil management practices

Soil sustainability can be influenced by various management practices including over-cultivation, decreased or increased water abstract, over-fertilization, excessive application of chemicals such as pesticides, insecticides, clearing natural vegetation etc. Thus, in order to combat soil pollution, sustainable soil management practices should be encouraged. Here, sustainable management practices mean, the practices that allow the present generation to meet the need, without compromising the ability of future generation to meet their need from the soil. A few instances of such practices are as per the following(*Voluntary Guidelines for Sustainable Soil Management*, n.d.) –

- Land-use changes such as deforestation or improper grassland-to-cropland conversionthat cause removal of surface cover and loss of soil

carbon should be avoided or carefully planned and appropriately implemented if unavoidable.

- Where appropriate, riparian buffer, buffer strips, wetlands, water harvesting andcover crops should be used/installed to minimize export of soil particles and associated nutrients.
- Increase organic matter content through practices such as: managing crop residues,using forage by grazing rather than harvesting, practicing organic farming, applying integrated soil fertility management and integrated pest management, applying animal manure or other carbon-rich wastes, using compost, and applying mulches or providing the soil with a permanent cover.
- Regularly monitoring the soil acidity and minimizing surface and sub-surface soil acidity by usingproper amendments such as lime, gypsum and clean ash.
- Implantation of sustainable agricultural practices such as matting of soil, contour farming, terracing and mulching.

8.6. Legislative measures to combat soil pollution

The need for protection and conservation of environment and sustainable use of natural resources is reflected in the constitutional framework of India. The Constitution under Part IVA (Art 51A-Fundamental Duties) states that it a duty on every citizen of India to protect and improve the natural environment including forests, lakes, rivers and wildlife, and to have compassion for living creatures. Further, the Constitution of India under Part IV (Art 48A-Directive Principles of State Policies) specifies that it is the duty of every state to protect and improve the environment and to safeguard the forests and wildlife of the country. (Vaish,2017).

As a result of the Stockholm Conference on human and environment 1972, the National Council for Environmental Policy and Planning was set up in 1972 within the Department of Science and Technology to establish a regulatory body to look after the environment-related issues. It is later evolved into a full-fledged Ministry of Environment and Forests (MoEF). Since, then number of

environment related laws and rules have been formulated, which monitors every aspect related to environmental pollutions.

Some of the important legislations that favours in protection of soil are as follows-

- The Water (Prevention and Control of Pollution) Act, 1974
- The Environment (Protection) Act, 1986
- Hazardous Wastes (Management and Handling) Rules, 1989
- The National Environment Tribunal Act, 1995
- Solid waste management rule, 2016
- E-waste management and handling rule, 2016

The above list of enactments indicates that there is no particular act or strategy, that have been sanctioned to secure land/soil from human impedance. It could be probably because the soil does not have any immediate route of toxic pollutant entry for the individual. However, by looking at the effect and magnitude of soil pollution, a need for a soil protection policy have been raised, that will straightforwardlydeal with the soil contaminants, their legitimate removal and reclamation of degraded soil.

TERMINAL QUESTIONS-

a) What are impacts of soil pollution on microbial community?
b) Discuss the soil washing techniques along with its advantages?
c) Discuss soil vitrification technique?
d) What do you mean by sustainable soil management processes?

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Unit 9: Climate Change

Unit Structure

9.0 Objectives

After reading this unit we probably become able to:

- Define climate change;
- Explain natural and human induced factors responsible for climate change;
- Describe various evidences of climate change and their sources;
- Describe the adverse impact of human activities on climate change; and
- Analyze the probable consequences and impact of climate change at global as well asnational level.

9.1 Introduction

Climate change can be defined more simply as any significant shift in the planet's climate that lasts for a long time. When analyzing or forecasting any climate condition for a location, a minimum time span of thirty years is typically taken into account.

Temperature and precipitation are two of the main components of climate. Climate change, according to the Intergovernmental Panel on Climate Change (IPCC), includes

"Any change in climate over time, whether due to natural variability or as a result ofhuman activity" (IPCC, 2001a).

The United Nations Framework Convention on Climate Change (UNFCC) defined climate change as:

"climate change refers to a change in climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is inaddition to natural climate variability observed over comparable time period" (IPCC, 2001a).

9.1.1 Global Change and Climate Change

Climate change is a significant and serious problem for humanity that has a negative impact on our ability to survive on our planet. The problem has gotten worse as a result of unchecked human activities that have caused changes in the local weather patterns. While everyone can feel changes in the weather because they occur often over the course of a day or a few hours, changes in the climate cannot be seen or felt in the same way because they occur over years, or over a long period of time.

The term "climate change" refers to changes in the typical weather encountered at a particular location throughout time, such as the typical weather, rainfall during the rainy season,

Today, there are lots of discussions on global change issues rather than merely discussing about climate change. While talking about climate change, there is a need for a discussion on global change for two reasons:

1) Climate change is one among many global changes that has been affecting the earth.
2) Climate change has been affecting and has been affected by many of the global change phenomena.

Global change is a transformation that takes place on a global scale, such as the buildup of carbon dioxide in the atmosphere, or that exhibits sufficient cumulative effects to have an impact globally, such as the extinction of local species that results in a loss of biodiversity globally. Solar output, plate tectonics, volcanism, the spread and

extinction of life, resource depletion, modifications to Earth's orbit around the sun, and adjustments to the tilt of the planet's axis have historically been the primary forces behind global change. There is mounting evidence that the growing human population's demand for energy, food, goods, and services, as well as the disposal of its waste products, is currently the primary cause of global change.

9.2 Approaches to Climatic Classification

The approaches to the classification of world climates depend on the nature of parameters which are selected to determine the identical combinations of climatic elements world over and the objectives and viewpoints of the persons involved in such classification. Generally, two basic climatic parameters of temperature (mean monthly and mean annual) and precipitation (both monthly and annual averages) became the basis of climatic classification schemes of early scientists mainly the botanists (more specifically plant physiologists) and geographers (mainly hagiographers, more specifically plant geographers). Such classification was based on relationship between vegetation, and temperature-humidity as it was conceived that the vegetations of a particular area or region were the function of temperature and humidity conditions of that area. The climatic types, thus, were based on the types of vegetation and were named after plants associations such as equatorial rainforest climate (evergreen trees), savanna climate (the region having coarse grasses and scattered dwarf trees on the margins of the tropics having seasonal rainfall-i.e. in summer season), taiga climate (having coniferous ever-green forests of the subarctic regions of North America and Eurasia), tundra Lliinate (having vast treeless almost ice covered plains of arctik regions of North America and Eurasia) etc. It may be mentioned that the basis of influences of climate on vegetation types and their distribution is still used for the classification of climates into major climate types, but it requires besides vegetation response to climate, other responses to climate to make the classification of world climates more scientific and elaborate e.g. human response to climate, effects of climate on denudational processes (rock weathering and erosion), climatic effects on soils and pedogenesis, requirements of water, temperature and humidity by agricultural crops etc. It appears from the above description that the effects of climates on vegetation, soils and pedogenesis, rock weathering,

9.3 Classification of Climates

The climatic conditions vary considerably both horizontally and vertically over the globe due to a host of variables awl hence the identification of such variations is required to determine groups of similar characteristics of climate. The climatic classification thus involves the groupings of identical weather and climatic characteristics in terms of insulation and temperature, atmospheric circulation and pressure, humidity and precipitation and their influences on vegetation, soil and fauna, of different regions of the world. The classification of Climatic Types is studied in detail. The aspects considered in this are:

(a) Intensity of sunshine and its variation with latitude

(b) Distribution of land and water.

(c) Ocean currents

(d) Prevailing winds

(e) Positions of high and low pressure areas

(f) Mountain barriers and

(g) Altitude.

1. Spatial Scales for Climatic Regions

Based on spatial scale of areal unit M.M. Yoshino has divided the world climates into four principal types e.g. (1) micro climate,(2) local climate (3) mesoclimate, and (4) macroclimate.

2. Microclimate

Microclimate refers to the climatic conditions of the smallest Spatial unit having a horizontal extent from one meter to 100 meters and vertical extent from the ground surface to 100 meters upward such as a vegetable garden, a single crop field, a single household, the area around a tree etc.

3. Local Climate

The local climate comprising a few microclimatic areas covers such spatial unit which has horizontal extent from 100 meters to 1000 meters and vertically extends from ground surface to 1000 meters wherein horizontal differences in climatic conditions are given more importance than vertical differences.

4. Mesoclimate

The mesoclimate incorporates several local climatic areas horizontally extending from 100 meters to 20 km and has vertical extent from the ground surface to the altitude of 6 kilometers. Topographically mesoclimatic area is homogeneous which is characterized by similar physical controls of weather and climate e.g. the Ganga delta, the middle Ganga plain, Konkan coastal plain, Malabar coast etc.

5. Macroclimate

Macroclimate also known as geoclimate or geographical climate, covers largest area of all the other three types of regional climate as referred to above. It covers the horizontal distance of more than 20 km (it may be several hundred kilometers) and vertically extends from the ground surface to and vertica more than 6 kilometers. Thus the macroclimatic area may cover even the entire continent or a large country like the USA, China, Russia, Brazil, India etc.

The important classification schemes studied are:

(i) Koppen's multi-tiered classification system

(ii) Thornthwaite's Classification

(iii) Genetic Classification and

(iv) Composite Classification.

1) Empirical Classification:

Empirical system of classification of world climates involves the consideration of the effects of climate on several environmental phenomena such as types and distributional patterns of vegetation, soils and soil forming processes, geomorphological processes, rock weathering, human beings (human health and physical growth), agricultural crops etc. two such syatems devised by Koppen and Thornthwaite are most widely known and are still relevant.

2) Koppen's Classification:

The German botanist and climatologist Wladimir Koppen presented descriptive scheme of the classification of world climates first in 1900 based on vegetation zones Of French plant physiologist Candol le presented in 1874. He revised his scheme in the year 1918 wherein he paid more attention to monthly and annual averages of

temperature and precipitation and their seasonal distribution. Koppen used the following five major vegetation zones of the world as identified by Candolle in 1874:

I. **Megathermal zone** represents such plants which depend on high temperature and humidity (and rainfall) throughout the year and hence there is no winter season. The plants are evergreen. The megathermal zone has the dominance of equatorial (tropical) rainforests having well developed vertical 5 strata.

II. **Xerophytic zone** represents such plants which thrive in hot and arid conditions. Such plants have suitable characteristic features to withstand extreme aridity. The xerophyte plants have their own moisture conserving devices such as long roots, thick barks, waxy leaves, thorns and little leaves so that they may avoid evapotranspiration and consequent loss of moisture from them.

III. **Mesothermal zone** represents mesotherm group of vegetation wherein plants are adapted to moderate temperature and precipitation. The temperatures for the coldest month are below 18^0C but above -3^0C while the average temperature of the warmest month is 22^0C.

IV. **Microthermal zone** represents such plants which can survive in the region having temperature of the coldest month below -3^0C but the average temperature of the warmest month remains above 10^0C but below 22^0C.Boreal deciduous and steppe vegetations are termed as microtherms.

V. **Hekistothermal zone** represents such plants which thrive on almost permanently ice covered arctic and polar areas, say tundra region. There is perfect relationship between vegetation and conditions of moisture in the soils. The characteristics lithosols of this zone (tundra biome) support only lichens and mosses.

Based on these five vegetation zones he divided the world climates into five principal types and designated them by capital alphabets A, B., C, D and E.

1. **A Climate**: A Climate represents humid tropical climates characterized by winterless season, warm and moist conditions throughout the year.
2. **B Climate**: B Climate represents dry climates where evaporation exceeds precipitation and there is constant water deficit throughout the year.
3. **C Climates**: C Climate represents humid mesothermal or middle latitudes warm temperate climates having mild winters.

4. **D Climates:** D Climate includes humid microthermal or cold forest climates characterized by severe winters, average temperatures of coldest and warmest months being below -3^{0}C and above 10^{0}C respectively.
5. **E Climates**: E Climate includes polar climates characterized by summerless season, average temperature of the warmest month below 10^{0}C .

3) Classification by Thornthwaite

The American climatologist Charles Warren Thornthwaite (1889–1963) developed a classification system for climates in 1931 and revised it in 1948. The system categorizes climates into groups based on the vegetation characteristics of those climates, with the vegetation being determined by precipitation effectiveness (P/E, where P is the total monthly precipitation and E is the total monthly evaporation). The P/E index, which is used to categorize five humidity provinces with corresponding vegetation, is created by adding the monthly P/E values.

A P/E index of more than 127 (wet) denotes a rain forest, 64–127 (humid) a forest, 32–63 (subhumid) a grassland, 16–31 (semi-arid) a steppe, and less than 16 (arid) a desert. A moisture index was added to the system in 1948. It uses an index of potential evapotranspiration (PE), which is derived from observations of air temperature and day length, to link the water demand by plants to the available precipitation. The moisture index is negative in arid areas where precipitation is below the PE. With accumulated monthly temperatures ranging from 0 to 127which indicates a frost climate (0) and a tropical climate (127), the method also employs a thermal efficiency index.

Climate classification for Thornthwaite By connecting the measurement of pan evaporation to temperature and precipitation, precipitation efficiency was calculated. The ratio 11.5 (rt-10) 1019 for each month, where r is the average monthly rainfall (in inches) and t is the average monthly temperature. Principal climatic group based on efficacy of precipitation is:

Humidity province	Vegetation	P/E index
A (Wet)	Rainforest	127
B (Humid)	Forest	64-127
C (Sub humid)	Grassland	32-63
D (Semiarid)	Steppe	16-31
E (Arid)	Desert	16

❖ Main climatic group based on Thermal efficiency

Thornthwaite developed a thermal efficiency index that is expressed as a positive deviation from freezing point for the monthly mean temperature. The annual sum (t-32) of the temperature ratios (T/E) for each month makes up the index.

Temperature	T/E index
A: Tropical	127
B:Mesothermal	64-127
C: Microthermal	32-63
D: Taiga	16-31
E:Tundra	1-15
F: Frost	0

Thornthwaite developed four indices to determine boundaries of different climatic types e.g.:

(i) Moisture index (Im),

(ii) Potential evapotranspiration or thermal efficiency index (PE),

(iii) Aridity and humidity indices, and

(iv) Index of concentration of thermal efficiency or potential evapotranspiration.

(i) Moisture Index (Im):

Moisture index refers to moisture deficit or surplus and is calculated according to the following formula:

$$Im = (100s - 60D)/PE$$

Where, Im = monthly moisture index S = monthly surplus of moisture

D = monthly deficit of moisture

The sum of the 12 monthly values of Im gives the annual moisture index.

Moisture index	Humidity provinces	cm	PE/IM	Thermal Province
>100	Perhumid(A)	>114	>44.9	Megatherm(A)
20-to 100	Humid(B1 toB4)	57-144	22.4-44.9	Mesotherm(B1 toB4)
0 to 20	Moist subhumid(C2)	28.5-57.8	11.2-22.4	Microtherm(C1 to C2)
-33 to 02	Dry Subhumid(c1)	14.5-28.5	5.6-11.2	Tundra(D)
-67 to -33	SemiArid(D)	<14.2	<5.6	Frost
-100 to -67	Arid(E)			

4) Genetic Classification:

Based on the causes of climatic variations and hence the genesis of different types of climates. The classification also involves explanations and interpretations of causal factors of different climatic types. Generally two approaches are more significant.

- Approach based on identified physical determinants of climates
- Air mass approach

Genetic classifications is being more descriptive and having less precisely, determined boundaries between two climatic types. Could not become popular and hence could not be widely used.

Oliver and Hidore, (2003) have divided the world climates into 3 major groups consists of climate types. Oliver and Hidore model of classification is popularly known as **Air Mass Model**. (Fig1)

	Wet ↔ DRY			
Hot	Tropical wet (Equatorial)	Tropical wet and dry	Tropical desert	Group I
Cold	Mid altitude wet	Mid altitude summer or winter dry	Mid altitude desert	Group II
	Polar wet	Polar wet and dry	Polar desert	Group III

(Figure 1: Air mass Model by Oliver and Hidore , 2003)

5) Composite Classification:

The scheme of classification of world climates by G.T. Trewartha falls under this category of classification. He identified 6 major climatic typesof first order designated as A,B,C, D, E, F climates out of which B climates were determined on precipitation criteria while others were determined on the basis of temperature.

(i) Tropical humid Climates (A Climates)

(ii) Dry Climates (B Climates)

(iii) Middle Latitude wet Climates (C Climates)

(iv) Micro thermal or Temperate Climates (D Climates)

(v) Boreal Climates (E Climates)

(vi) Polar Climates (F Climates)

9.4 Indicators of Climate change

There are several theories and causes of climatic changes. In Climatology all of them are studied to understand the past and predict the future. There are several kinds of indictors reflecting the climatic changes. The notable ones are:

(i) Biological Indicators (Floral, Faunal remain in fossils)

(ii) Geological Indicators (Sedimentary deposits)

(iii) Cryogenic Indicators (ice ages, glaciers, ice sheets)

(iv) Tectonic Indicators (Sea floor spreading and sea level changes)

(v) Geomorphologic Indicators

(vi) Historical records of droughts and floods and migration of man and animals.

Dendrochronology is one aspect coming under these analyses. The Global Warming refers to increase in global surface and atmospheric temperature affecting the global radiation balance. It needs a sound weather forecast methodology. Weather forecasting is a part of climatic studies.

(i) Biological indicators: The fossilized organic remains of plants and animals (i.e. organic residues) provide significant evidences and proxy data for contemporary Climatic conditions mainly temperatures and moisture. It may be mentioned that the nature and types of organisms and their habitats are deter-mined by a climatic type. After their deaths the plants and animals are preserved in the forms of fossilized organic remains in the contemporary and subsequent geological formations. The analysis of such organic fossils through the application of proper techniques (e.g. carbon dating, oxygen isotope analysis, pollen analysis, dendrochronology etc) reveals important clues to decipher contemporary past climates. The biological indicators fall under two broad categories:

- **Plant (floral) indicators**: Presently, there is very close correspondence between the distribution of climate types and vegetation types. Based on the principle of **uniformitarian's**, and the **'concept of 'present is key to the past'** it may be opined that similar relationships and conditions might have prevailed throughout geological history of the earth. Thus, on the basis of fossilized plant remains, the vegetation type is inferred and such inferred information (proxy data) provides clue to determine the nature of climate. For example, the

existence of coals having remains of tropical forests, in the north-west Europe and Great Britain remind us hot and humid climate of these areas during Jurassic period. The plant physiology gives sufficient information about climatic conditions. For example, the fossil remains of plants having long roots, thick barks, waxy leaves, thorns, little leaves etc. indicate warm and dry climate (warm desert climate), while plants having drip leaves are indicator of warm and very moist conditions (tropical rainforest climate). The cryophyte vegetations are web adapted to severe cold conditions as they develop such unique features which enable them to withstand extreme cold conditions. Thus, the fossil remains of cryophyte plants indicate cold climatic conditions (tundra climate).

- **Pollen analysis** The study of Pollen grains and spores of plants helps in identifying the types of vegetation on the basis of Pollen grains, and the vegetation types give clues for deciphering the climate in which that vegetation type might have developed is known as **Palynology**. The pollen analysis involves the inference of climatic conditions on the basis of dating of fossilized pollen grains preserved in the inorganic sediments layers. It may be noted that pollen grains of flowering plants are very durable organic substances which are duly preserved by the nature and pollen grains which are distributed by wind in wide areas having similar type of vegetation. The identification of plant species on the basis of their pollen grains helps in the determining the climatic conditions.
- **Dendrochronology:** Dendrochronology is the science, which deals with 'the study of the annual rings of trees in determining the dates and chronological orders of past climatic events'. The ring growth of the trunk and stem of a tree provides significant clues for detecting seasonal rhythms of climate during the life time of the concerned tree. The thickness and spacing, and colour of growth rings indicate climatic conditions and rate of annual, growth of trees. The widely spaced thick growth rings denote warm and moist climate with sufficient rain 11 to support luxurious and quick growth of trees, while narrow and closely spaced tree growth rings denote and climate and poor growth of trees. The colons of growth rings also denote seasonal weather conditions.

'The abrupt change from light to dark-coloured rings (growth rings) delineates the annual increments of growth' (Oliver and Hidore, 2003).

- **Faunal Indicators:** Identification and analysis of fossilized invertebrate animal remains embedded in the sedimentary formations provides significant clues about the climatic conditions that existed during the period of their survivals. In this respect the physiological characteristics of fossils of invertebrate animals (without backbones) and their chemistry are of vital significance wherein two techniques are used to determine their age, namely
- **Radiocarbon dating (C-14 analysis):** The radiocarbon dating method or carbon-14 analysis requires obtaining of cores of mud layers containing animal and plant fossils from the floors s and the dating of oceans, lakes, and river valley of the fossils is accomplished through the analysis of carbon-14 and carbon-12 contained in the skeletons of the fossilized animals. It may be mentioned that skeletons of dead animals 'contain both ordinary carbon and minute trace of isotope carbon-14. The proportion of carbon-14 to carbon-12 remains fixed while the organism is alive. After it dies the carbon-14 begins to decay; by knowing the ratio of carbon-12 to carbon-14, one can determine the age of the shell' (Oliver and Ilidore, 2003),
- **Isotope analysis:** The isotope analysis of the chemistry of skeletons of fossilized animals also helps in determining palaeoclimates on the basis of temperature and moisture conditions which are inferred from the body chemistry of dead animals. Oxygen has three non-radioactive isotopes e.g. O^{17}, O^{18} and O^{16} out of which the first two isotopes are not very common but the last one is common and normal isotope. After the evaporation of water, these isotopes crystallize at different rates in the shells i.e. O^{18} isotope settles down more rapidly theta the O^{16} isotope because the latter is lighter than the former isotope (O^{18}). It may be mentioned that the rate of crystallization of oxygen isotope is controlled by temperature. The number of settling O^{18} isotope decreases with increase in the temperature of ocean water. Thus, on the basis of number of oxygen isotopes contained in the shells of dead animals the prevailing temperature at the time of the existence of particular animal is determined. For this purpose again the cores of mud layers from

the floors of oceans, lakes and river valleys are taken out, oxygen isotopes of shells of each mud layer are determined, temperature condition for each mud layer is inferred and finally temperatures prevailing at the time of deposition of animal skeletons and mud layers are used to ascertain climatic changes.

(ii) Geological Indicators

Geological indicators (evidences) of palaeoclimates include lithological characteristics of mainly sedimentary deposits such as lacustrine deposits (varves), evaporites, lime-stones and coal seams, marine deposits (sea floor deposits), soil profiles etc.

Evaporate deposits, represented by salt deposits, occur when climate is characterized by high temperature and aridity wherein evaporation exceeds precipitation. In such circumstances water is evaporated and salt contents are left behind.

Limestone's ($CaCO_3$) containing calcium carbonates are deposited in tropical warm oceanic water and hence the occurrence of limestones in the regions having cold climates denotes the fact that the concerned region was under tropical warm climate at the time of limestone deposition.

Duricrusts arc indurated hardened surfaces of different kinds such as laterites, silcretes, calcretes, alcretes, ferricretes etc. depending on the dominance of constituent minerals.

Pedogenic criteria used to decipher past climates, include the analysis of palaeosols and fossils of plants and animals therein. The alluvial soils buried in older flood plains give indication of moist climate and the dominance of fluvial processes.

(iii) Cryogenic indicators

Cryogenic indicators are related to the proxy data from the evidences of glaciation, glaciers and ice sheets. The science dealing with processes of glaciation and glaciers is known as **glaciology**. The processes of glaciations and deglaciation provide significant proxy data for climatic changes and fluctuation. The period of widespread glaciations of larger areas of the globe is called great ice age which comprises of several glacial and interglacial periods. The glacial period denotes onset of cold climate and advance of 'ice sheets while interglacial periods indicate relatively warmer periods when ice sheets retreat.

Ice sheets and **ice cores** are most significant cryogenic indicators of palaeoclimates. It may be remembered that the ice sheets are formed by the deposition of several layers of ice. The accumulated snow from the annual snowfall is compressed and is changed to ice wherein the air bubbles and atmospheric dusts are trapped. Thus, every year a layer of ice is deposited upon underlying ice layer.

(iv) Tectonic Indicators

The tectonic movements involving movements, pole wandering, continental drift, orogenesis, palaeomagnetism, topographic features etc. and seafloor spreading and sea level changes are significant indicators of palaeoclimatic, changes. The changes in global pattern in plate motions cause changes in climates at global scale.

(v) Geomorphological indicators

The geomorphological processes and landforms resulting therefrom have been directly related to particular climatic type on the concept that each climatic type produces its own characteristic assemblage of landforms and set geornorphological processes which shape them on the basis of the following themes:

- Landforms differ significantly in different climatic regions.
- Spatial variations of landforms in different climatic regions are because of spatial variations in climatic parameters (e.g. temperature, humidity, precipitation etc.) and their influences on weathering processes, erosion dynamics and surface runoff.
- Quaternary climatic changes could not obscure relationships between landforms and climates.

Sea Level Fluctuations: Fluctuations in sea levels are considered significant indicators of past climatic changes, Sep level changes are of two types, namely positive change marked by rise in sea level above datum line, and negative change denoting fall in sea level below datum line. Changes in sea level are effected by

Tectonic movements: The tectonic movements cause rise in sea level when there is upward movement of sea floor (ocean bottoms) or down warping of coastal areas whereas fall in sea level is caused by downwarping leading to subsidence of sea floor or upwarping of coastal lands. It may be mentioned that tectonically induced changes in sea levels are very slow.

Climatic changes: The Climatically induced changes in sea levels are rapid and are effected by glacial age and advancement of glaciers and ice sheets (fall in sea levels) and deglaciation leading to retreat of glaciers and ice sheets (rise in sea levels). The sequences of rise and fall in sea levels during Pleistocene Ice Age have revealed several phases of glacial periods.

(vi) Indicators of Historical Records:

The recorded events during the existence of human species provide valuable data for reconstructing the palaeoclimatic history (**palaeochimochronology**) for the past 6000 years. It may be mentioned that the recorded past events are related mostly to extreme events of weather conditions rather than regular weather conditions. Such extreme weather events include freezing of rivers and lakes, unprecedented floods and droughts leading to famines, mass exodus of human migration deserting their settlements etc. A few examples will be sufficient to demonstrate the significance of such indicators of climatic changes. The description of climochoronology of the world may be attempted in the following heads:

(1) Climatic changes during geological periods

(2) Climatic changes during Quaternary periods

(3) Climatic changes in the recent past (about past 1000 years or so).

9.5 Sources of Climate Change

Do you know that since the Earth's creation, climate change has occurred frequently? You may then be wondering why we are raising such a fuss about this. This is due to the fact that climate change in the modern world is anthropogenic, or to put it another way, caused by human actions. Evidence points to natural processes as the cause of earlier climate change. Therefore, we will briefly cover a variety of natural causes that contributed to climate change over the course of various geological periods in the history of the world at the beginning of the module. We will go into great detail about the recent anthropogenic activities that have contributed to climate change.

The causes or sources of climate change can be divided into two categories:

- Natural
- Anthropogenic

(1) Natural Sources of Climate Change

Short-term climate change is caused by some of the reasons listed below, and long-term climate change is caused by others. Solar fluctuation, modifications to the Earth's orbit and tilt, plate tectonics, and biological evolution are some of the main natural causes of climate change.

Solar Variability: The output of solar energy varies, which causes this. You may have read that the sun's energy output varies a little bit throughout time. Data collected via satellite has been used to measure this. Both the day and the solar cycle, variations in the overall output have been seen. The climate of Earth may be directly impacted by these fluctuations.

Changes in Earth's Orbit and Tilt:

Another significant natural factor that contributed to climate change was this. You may have read that the earth's orbit often varies over a 100,000-year cycle. The orbit typically changes from being almost circular to elliptical. As a result, the tilt of the Earth's axis has changed by 21.8 to 24.4 degrees. Consequently, the solar energy budget of the earth has changed. In other words, the amount of solar energy that various parts of the Earth get used to vary. Now, the northern hemisphere is farther from the sun in the summer and nearer to it in the winter. As a result, it receives 5% less summer sunlight than it did 12,000 years ago. Seasonal fluctuations increase as tilt increases. It's called the **Milankovitch cycle** (Refer to Figure 2). Geophysicist and astronomer Milankovitch from Serbia proposed a theory for the aforementioned phenomenon.

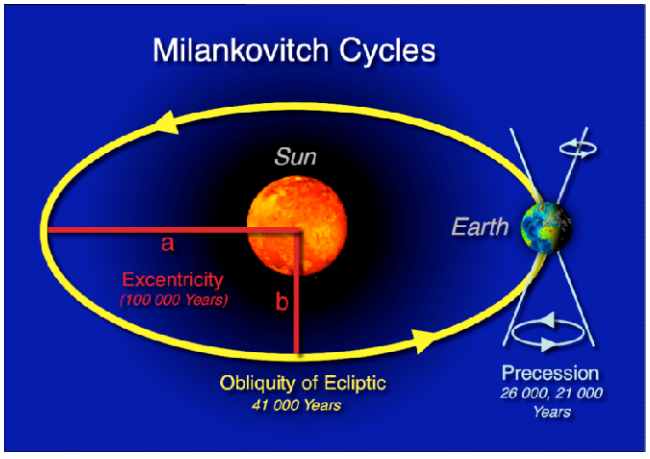


Figure 2: Climate Change due to Changes in Earth's Orbit and Tilt

Source: https://commons.wikimedia.org/wiki/File:Milankovitch-cycles_hg.png

Plate Tectonics:

According to continental drift and plate tectonic theory, the majority of the Earth's land mass was once one single continent called Pangea, which was encircled by one enormous body of water called a panthalas. The continents and ocean basins we see today were gradually formed as pieces of it drifted apart over time. Global climate has been significantly impacted by the shift of land mass and ocean area.

9.6 Biological Evolution

This organic process primarily occurred during the development of photosynthesis-dependent organisms. Several billion years ago, the main components of Earth's pre-life atmosphere were carbon dioxide and methane. Because photosynthetic organisms used up carbon dioxide and produced oxygen, the atmospheric concentrations gradually changed from carbon dioxide and methane to nitrogen and oxygen.

Climate Change due to Anthropogenic Activities

Today's climate change is primarily due to anthropogenic activities. There was lots of scientific research that took place over the last two hundred years that helped in concluding about the present climate change is due to anthropogenic activities.

Scientific Study to Establish Human Induced Climate Change: As we know, today's climate change is due to presence of excessive greenhouse gases in the atmosphere due to human activities. This led to increase in temperature on the earth surface due to greenhouse effect. Do you know the scientist who identified the problem created by greenhouse effect? The French mathematician, Joseph Fourier highlighted the greenhouse effect. Fourier realized that the earth's temperature is determined not only by the radiation absorbed by, and emitted from the earth, but also by the existence of the atmosphere. The atmosphere absorbs some of the radiated heat and acts as a blanket over the Earth that maintains the temperature higher than it would otherwise be.

The next major breakthrough was made in 1860 by the British scientist John Tyndall in terms of measuring the absorption of radiation by different gases. This led to the remarkable discovery that the most prevalent gases in the atmosphere i.e. oxygen and nitrogen weren't absorbing any of the energy at all. Only the minor gases in the

atmosphere, i.e., carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and water vapour, were doing so. These gases are called greenhouse gases (GHG).

The Swedish scientist, Svante Arrhenius was the first person to estimate the extent to which increases in atmospheric carbon dioxide increase Earth's surface temperature. This is also known as Arrhenius effect. Presently, studying climate system is much more advanced due tothe advancement in information and communication technology aided by space technology.

Global Warming and Anthropogenic Activities: Till now, you might have realized that global warming is most commonly associated with human interference, specifically the release of excessive amounts of greenhouse gases. These gases, act like a greenhouse around the earth. This means that these gases allow the heat from the Sun to enter into the atmosphere, but do not allow the heat to escape back into space. In other words, more increase in the greenhouse gases, the larger is the percentage of heat trapped inside the earth'satmosphere. You might know that the earth would have not been inhabitable without the presence of some naturally occurring greenhouse gases (GHG). This is because without these gases, no heat would be trapped in the atmosphere, so the earth would be extremely cold. It is estimated that the average temperature of the earth would be about -17^0C without greenhouse effect which is not at all the condition for the growth of biota. Naturally occurring greenhousegases (not fluorinated gases) are good in naturally occurring amounts; it's when people start contributing excessive amounts of these that greenhouse gases become a problem. With excessive greenhouse gas build-up, the earth's atmosphere warms to unnatural temperatures.

Let us understand how various human activities contribute in increasing these GHGs.

How do Human Activities Contribute to Climate Change? Different anthropogenic activities lead to emissions of four principal greenhouse gases: carbon dioxide, methane, nitrous oxide and the halocarbons (a group of gases containing fluorine, chlorine and bromine). These gases accumulate in the atmosphere and have been increasing with the passage of time. The most significant aspect about the increases in all of these gases is that they have occurred in the industrial era which is not more than 300 years old. This is because of influence of human activities particularly in recent

centuries. It is so significant that it has been affecting all the living organisms on the earth.

Carbon dioxide has been increasing from the utilization of fossil fuels in transportation, building heating/ cooling and in the manufacture of cement and other goods. Deforestation releases CO_2 and reduces its uptake by plants. Carbon dioxide is also released in natural processes such as the decay of plant matter.

Methane has increased as a result of human activities related to agriculture, natural gas distribution and landfills. Methane is also released from natural processes that occur, for example, in wetlands.

Nitrous oxide is emitted by human activities such as fertilizer use and fossil fuel burning. Natural processes in soils and the oceans also release N_2O.

Halocarbon gas concentrations have increased primarily due to human activities. Principal halocarbons include the chlorofluorocarbons (e.g., CFC-11 and CFC-12), which were used extensively as refrigeration agents and in other industrial processes before their presence in the atmosphere was found to cause stratospheric ozone depletion.

9.7 Sources of Evidences about Climate Change

When we discuss about the science of climate change we generally look for evidences and causes responsible for climate change. As a result of which the scientific community including geographers look for three key elements. These three key elements are “the study of past climates, the measurement of current climate change and the modelling and projections of future climate scenario.” (Christopherson and Birkeland, p. 316)

Scientists all over the world have been systematically compiling and analysing different climate related parameters to ascertain about the changing climate. They have also made an attempt to ascertain that the present climate change is human induced. The IPCC, since its inception in 1988 has been working as the international scientific organization coordinating global climate change research, climate forecasts, and policy formulation by engaging in collaboration of scientists and policy experts from many disciplines across the globe. Therefore, this assertion is based on certain facts rather

than any speculation or politically motivated. Some of the sources of evidences are as follows:

Evidences of Climate Change

Climate scientists have been constantly engaged in gathering information on key parameters of climate that indicates that some of these parameters have been unequivocally reflect warming of climate. These evidences are gathered from various sources for last hundred years as well as in extensive details for the last two to three decades. Various sources used forgathering such information are innumerable weather stations across the globe, satellites, ships, aircrafts, weather balloons and buoys. These evidences are collated and trend analysis has been undertaken by numerous scientists engaged at national and international level.

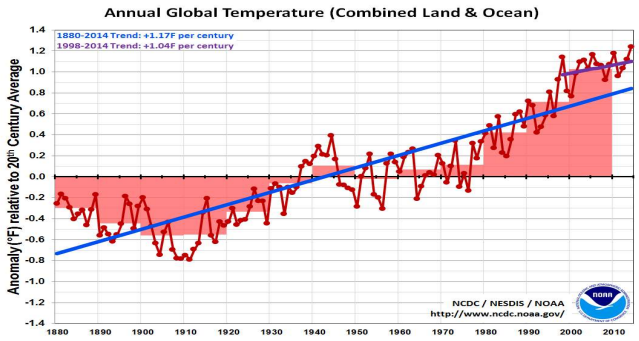
At the international level, these researches are compiled and global trends have been reported by the Intergovernmental Panel on Climate Change (IPCC) in the form of Assessment Reports. IPCC since its origin in 1988, has already been published these assessment reports. So far, five reports have been published in chronological order. The latest Fifth Assessment Reports have been published between September 2013 and April 2014.

As mentioned above, there are certain parameters that provide indication of warming of climate. Some of these indicators are as follows:

- Increasing temperatures over land and ocean surfaces;
- Melting glacial ice and sea ice;
- Rising sea level; and
- Increasing humidity. (Christopherson and Birkeland, p. 316)

Let us have a detailed discussion on these indicators of climate change in the following section.

Figure 3: Global Temperature Change 1880-2004



Source: https://www.ncdc.noaa.gov/monitoring-content/sotc/global/2014/ann/timeseries/trend-since-1998.png

Increasing Temperatures over Land and Ocean Surfaces: If we analyze temperature data in terms of hemisphere since 1880, it has been observed that the years with the warmest land-surface temperatures were 2005 and 2010 in the Northern Hemisphere. In the Southern Hemisphere, 2009 was the warmest. It has also been observed that the period from 2000 to 2010 was the warmest decade since 1880 Refer to Figure 3). The data from long-term climate reconstructions of temperature point to the present time as the warmest in the last 120,000 years. These reconstructions also suggest that the increase in temperature during the twentieth century is extremely likely (within a confidence interval of greater than 95%–100 %) the largest to occur in any century over the past 1000 years. Record- setting summer daytime temperatures are being recorded in many countries. According to National Oceanic Administration of America (NOAA) ocean temperatures have also been rising. According to NOAA sea surface temperatures increased at an average rate of 0.07 C° (0.13 F°) per year from 1901 to 2012 as oceans absorbed atmospheric heat. This rise is reflected in measurements of upper-ocean heat content, which includes the upper 700 m (2296ft.) of ocean.

Melting of Glacial and Sea Ice: You might have read in the newspapers, magazines or heard from TV, Radio etc. that glacier in Greenland and Antarctica have been receding due to fast rate of melting.Is this a fact? If yes, what are the reasons responsible for such situation? As discussed in the previous paragraph thatthere has been increase in surface temperature both at land and sea.This rise in temperature has a direct relationship with the melting of glacial and sea ice.

As temperatures rise in Earth's atmosphere, glaciers are losing ice mass, shrinking in size. This process is known as glacial retreat. Earth's two largest ice sheets, in Greenland and Antarctica, are also losing icemass. This is evident from the satellite records. Analysis of satellite data of July 2012 revealed that 97% of the ice sheet's surface was melting. This was the greatest extent in the 30-year record of satellite measurements. Another analysis related to summer melt of the Greenland ice sheet has also revealed that it has increased 30% from 1979 to2006. On the basis of these evidences, scientists now estimate that between one- and two-thirds of Arctic permafrost will thaw over the next 200 years. As you know, these permafrost reserves took thousands of years to form.

Similar kind of observation has also been noticed in relation to sea ice. Maximum sea ice cover in the world is found in the Arctic Sea. The extent of Arctic Sea ice varies over the course of a year. Every summer, some amount of sea ice thaws whereas in winter, the ice refreezes. It has been observed with the help of satellite data that the minimum extent of summer sea-ice occurs in September whereas maximum extent of winter sea-ice occurs in the months of February or early March. However, analysis of satellite data revealed that this has declined since 1979(Refer to Figure 4). September sea ice is declining at a rate of 11% perdecade in comparison to the 1979– 2000 average and reached its lowest extent in the modern record in 2012. The accelerating decline of summer sea ice, in association with record losses of sea ice in 2007 and 2012, suggests that summer sea ice may disappear sooner than predicted by most models. Some scientists have also estimated an ice-free summer Arctic Ocean within the next few decades.

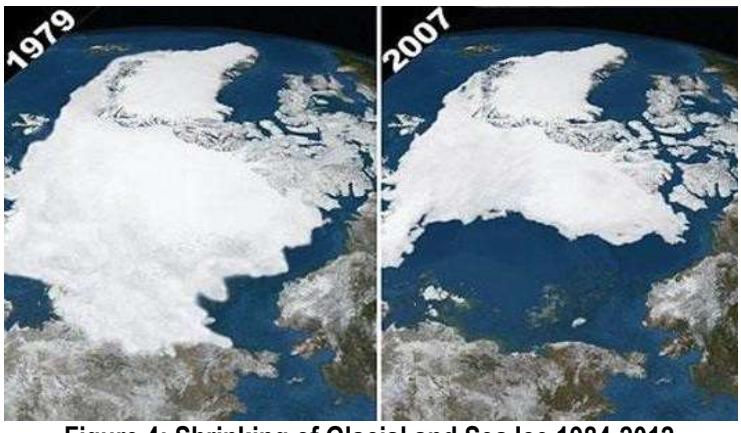


Figure 4: Shrinking of Glacial and Sea Ice 1984-2012

Source: https://scitechdaily.com/images/arctic-sea-ice-comparison.jpg

Rising Sea-Level: This is another important indicator of climate change. It has been observed that sea level is rising more quickly than the prediction simulated by most of the climate models. During the last century, sea level rose 17–21 cm (6.7–8.3 in.). However, this rise is not uniform across the globe. A greater rise has been observed in some areas like Atlantic coast of U.S. than at any time during the past 2000 years. How did the scientists arrive at such conclusion? Do you have any idea about the tools used for assessing the rise in sea level? Generally we use tidal gauges and satellites to generate such kind of data. Tidal gauge records from 1901 to 2010 show that sea level rose at a rate of 1.7 mm (0.07 in.) per year. Satellite data for the period 1993 - 2013 show that sea level rose 3.16 mm (0.12 in.) per year. This rise is primary due to two major factors that are presently contributing to sea-level rise. About two-thirds of the rise comes from the melting of glaciers and ice sheets whereas the rest one third comes from the thermal expansion of seawater due to absorption of atmospheric heat and expand in volume.

Increasing Humidity and Extreme Events: It has been observed that global average specific humidity has increased by about 0.1 g of water vapour per kilogram of air per decade since 1973. This change is consistent with rising air temperatures, since warm air has a greater capacity to absorb water vapour. A greater amount of water vapour in the atmosphere affects weather in a number of ways and can lead to “extreme” events involving temperature, precipitation, and storm intensity. According to the World Meteorological Organization, the decade from 2001 to 2010 showed evidence of a worldwide increase in extreme events, notably heat waves, increased precipitation, and floods. However, to establish a strong linkage between trends related to extreme weather and climate change requires data for a longer timeframe than what is now available.

These above mentioned change have differential impacts in terms of geographical locations, sectors of economy and socio-economic groups. Therefore, some of the major impacts/consequences of climate change are mentioned for two levels. One is at macro scale i.e. at global level and the other at micro-level i.e. at national level.

Some of the major observations of **Fifth Assessment Report (2013) by IPCC** are given below:

Observations of Changes in Climate at Global Level

Some of the highlights of the 5th Assessment Report are as follows:

- Each of the last three decades has been successively warmer at the earth's surface than any preceding decade since 1850.
- Ocean warming dominates the increase in energy stored in the climate system, accounting for more than 90% of the energy accumulated between 1971 and 2010. Further uptake of carbon by the ocean will increase ocean acidification.
- Over the last two decades, the Greenland and Antarctic ice sheets have been losing mass, glaciers have continued to shrink almost worldwide, and arctic sea ice and northern Hemisphere spring snow cover have continued to decrease in extent.
- The rate of sea-level rise since the mid-nineteenth century has been larger than the mean rate during the previous two millennia. Over the period 1901–2010, global mean sea level rose by 0.19 m (0.6 ft).
- The atmospheric concentrations of carbon dioxide (CO_2), methane, and nitrous oxide have increased to levels unprecedented in at least the last 800,000 years, primarily from fossil-fuel emissions and secondarily from net land-use-change emissions. The ocean has absorbed about 30% of the emitted anthropogenic carbon dioxide, causing ocean acidification.
- Total radiative forcing is positive and has led to an uptake of energyby the climate system. The largest contribution to total radiative forcing is caused by the increase in the atmospheric concentration of CO_2 since 1750.
- Warming of the climate system is unequivocal. Many of thetemperature changes observed since the 1950s are unprecedented over decades to millennia. It is extremely likely (95%–99%) that human influence has been the dominant cause of the observed warming since the mid-twentieth century.
- Climate models have improved since the Fourth Assessment Report. Models reproduce observed continental-scale surfacetemperature patterns and trends over many decades, including the more rapid warming since the mid-twentieth century and the cooling immediately following large volcanic eruptions.

- Continued emissions of greenhouse gases will cause further warming andchanges in all components of the climate system. Limiting climate change will require substantial and sustained reductions of greenhouse gas emissions.
- Changes in the global water cycle will not be uniform.
- The contrast inprecipitation between wet and dry regions and between wet and dry seasons will increase.
- Global mean sea level will continue to rise. The rate of sea-level rise will very likely exceed that observed during 1971–2010, due to increased ocean warming and increased loss of ice mass from glaciers and ice sheets (Climate change 2013, IPCC).

9.8 Observations of Changes in Climate at National Level

Indian Network for Climate Change Analysis (INCCA) in the recently released report titled "Climate Change and India: A 4x4 Assessment - A Sectoral and Regional Analysis for 2030s" assess differential impacts on the basis of observed climate change and climatechange projections for the year 2030s on selected sectors such as water resources, agriculture,forests and human health of selected four distinct geo-ecological regions of India that are sensitive to climate change. These regions are the Himalayan region, North-Eastern region, Western Ghats and Coastal regions.

According to the report, "The choice of the sectors and regions is in conformity with the significance and importance of the climate sensitive sectors of the economy that cover the wellbeing and livelihoods of the large population residing in these regions" (INCCA 2010, p.12). But the complete extent and level of climate change impacts on India are still to be studied because it is very diverse and complex in nature. This is because vulnerability to climate change increases due to "low adaptive capacity to withstand the adverse impacts of climate change due to high dependence of the majority of the population on climate-sensitive sectors like agriculture and forestry, poor infrastructure facilities, weak institutional mechanisms and lack of financial resources" (Shukla et al. 2003, p.13).

Impact of Climate Change in India: India, being a party of U.N. Framework Convention on Climate (F.C.C.C) published its first official document on impact of emission of green house gases on present and future climate of the country on June 1,

2004. The total annual emission of GH gases amounted to one million tonnes giving per capita emission of1.3 tonnes/year. The overall global rise of temperature of 0.4^0C has caused10-122% increase in monsoon rain in the west coast, northwest regions and north Andhra Pradesh but 6-.8% decline in M.P. and adjoining areas, north-east regions and parts of Gujarat and Kerala. The temperature is likely to increase by 2-4°C from 1994 level by 2040 AD. Minimum temperature will rise by 4°C across the country by 2040. There will be decrease in rainy days by 15 days over major parts of the country. The rising temperature would dry up key river basins of India after 2040 AD (Down to Earth, July 31, 2004y,

Climate Change and Indian Efforts: The developmental needs of the country coupled with energy needs are likely to increase India's GHG emissions in the decades to come. However, India is also prone to adverse effects of climate change including subsidence of coastal areas. Therefore, India has been participating in climate change programmes and fulfilling its commitments under the international law. India has actively participated in Clean Development Mechanism (CDM) established under Kyoto Protocol. India has also ratified Second Commitment Period targets under the Kyoto Protocol in August 2017. A brief analysis of India's efforts in this direction is given hereinafter.

India has not enacted a legislation to deal with climate change however, Government of India constituted Prime Minister's Council on Climate Change in June 2007. The main aim of this Council is to advise the government regarding climate change policies and effects. The objectives of PM's Council on Climate Change are as under:

- To coordinate National Plan for assessment, adaptation and mitigation of Climate Change
- To advise the government
- To facilitate inter-ministerial coordination

Since its establishment, the Council has been reconstituted by successive governments to advise the national government regarding climate change action plan and for adaptation and mitigation of climate change. The Council is chaired by the Prime Minister and various Union ministers like Finance Minister, External Affairs Minister, Power Minister, Minister of Environment, Forests and Climate Change,

Minister of Agriculture etc are member's along with members from TERI (The Energy and Resource Institute) and BEE (Bureau of Energy Efficiency).

9.8.1 National Action Plan on Climate Change

India has also launched a National Action Plan on Climate Change (NAPCC) in 2008. The Action Plan consists of eight national Missions which are briefly discussed hereunder:

- **Jawahar Lal Nehru National Solar Mission** – Mission was launched in 2008 to establish India as a global leader in solar energy to contribute towards clean energy and clean development. The aim of the mission is to develop 20000 MW of solar energy. To facilitate the generation of solar energy, 20 million square meter thermal collector area is required. The country has also established Clean Energy Fund in 2010 and levied cess on Coal i.e. Clean Energy Cess which has been renamed as Clean Environment Cess in 2017. The purpose of this fund is to finance clean energy project and promote clean energy. To further contribute towards clean energy, Electricity Act, 2003 has mandated purchase of grid based power from renewable sources.
- **National Mission for Enhanced Energy Efficiency** – The aim of this mission is to ensure energy efficiency improvement in large energy intensive industries and to facilitate Energy Efficient Economic Development. For this purpose, country is focussing on development and use of energy efficient appliances and equipments e.g. super efficient ceiling fans have been developed. India has also been promoting and distributing LED bulbs so as to promote energy efficiency and thereby lower energy consumption. Target is to save fuel and avoid capacity addition.
- **National Mission on Sustainable Habitat** – The target of this mission is to make cities sustainable by improvements in energy efficiency and by promoting use of public transport. The chief features of this mission are
    - Extension of Energy Conservation Building Code, 2007 to all new and existing buildings
    - To optimize energy demands of large commercial buildings
    - Shift to energy efficient and convenient Public Transport

- Utilization of Urban Waste to derive fuel – Refuse derived Fuel (RDF)

- **National Water Mission** – One of the components of NAPCC is national water mission. The aim of this mission are:
  - To Conserve Water, minimize wastage and equitable distribution of water
  - Creation of Ground Water Monitoring Wells
  - Development of water database
  - India has made efforts for revision of National Water Policy, 2012 in line with these aims
- **National Mission for Sustainable Agriculture** – This mission aims at developing sustainable agriculture as a climate resilient system and at the same time to ensure food security which is an important need of developing country like India. For the purpose, the mission promotes
  - On farm water use efficiency
  - Soil health management
  - Development of degraded land and
  - Micro irrigation
- **National Mission for Sustaining the Himalayan Ecosystem** – Himalayan Ecosystem is very important not only for India but for the world at large and it is important that adequate efforts are made to sustain the Himalayan Ecosystem. For this purpose, this mission has promoted following steps:
  - Sustaining and safeguarding Himalayan glaciers and mountain ecosystems
  - Protection of Biodiversity, wildlife of Himalaya
  - Identification of institutions for studies on Himalayan ecosystems
  - Creation of centres for bridging knowledge gaps
  - Identification and training of experts
  - Creating and strengthening Observational network
- **National Mission for a Green India** – Green India is an important mission on which both the Union and State governments have been working in cohesion. States have been asked to make State level plans for the same and many states have submitted and are implementing their plans. The aim of this mission in consonance with National Forest Policy is to increase the forest cover on 5 million hectares of forest and non-forest land and also to increase forest based livelihood.

- **National Mission on Strategic Knowledge for Climate Change** – The purpose of this mission is to promote research and development on climate change and the likely impact of climate change on India so as to make mitigation and adaptation strategy accordingly. The mission aims at providing and ensuring funding for research on climate change.

The PM's Council on Climate Change and Ministry of Environment, Forests and Climate Change is working on strengthening and revamping NAPCC and it is expected to launch three more missions under NAPCC on Impact of Climate Change on Health, Coastal Zones and regarding Waste to Energy (The Hindu, 2017).

9.9 International Corporations Efforts

The international communities are well aware and are seized of the globa1 environmental and ecological problems and various efforts have been initiated to control global warming and halt probable climatic changes. There are several organizations, government agencies, intergovernmental agencies, non-government organizations (NGO) which have undertaken various action plans and projects to study the relationships between an and environment, interactions between man and nature, the environmental problems resulting there from and remedial measures therefor.

The formulation of Montreal Protocol in September, 1987 under the leadership of UNO-sponsored United Nations Environment Programme (UNEP), the international conference on 'depletion of ozone layer' in London, held from March 5 to 7, 1989, wherein government officials, scientists and industrialists of 180 countries participated, international conference on ozone depletion held in London in 1990 etc, for restricting the production and consumption of ozone depleting chlorofluorocarbons (CFCs) etc, are a few examples which reveal the seriousness of international communities for their active cooperations in tackling the global environmental problems but it is painful to pen down that still the political gimmicks, international politics, self interest and greed are the taboos of such efforts and cooperation's. Several international conferences, seminars, symposia, workshops etc. for the maintenance of environmental quality, ecological balance, ecosystem stability and biodiversity have been attended by different countries, United Nations, voluntary, non-government and government organizations and several agreements and-declarations have been signed. The following are the important conferences, protocols, agreements and declarations.

- First World Climate Summit, 1979 in Geneva (Switzerland)
- Conference on Industries and Climate, 1980, in Vienna (Austria).
- Vienna Convention (Austria), 1985/ for the protection and maintenance of ozone layer.
- Agreement on Montreal Protocol, Montreal, Canada, 1987 (September) for reduction of the production and consumption of ozone depleting chlorofluorocarbons (CFCs) in order to check the depletion of ozone layer.

(1) First Earth Summit (Rio Summit)

United Nations Conference on Environment and Development (UNCED), better known as **Earth Summit** or simply **Rio Summit** was organized from june 3 to 14, 1992, in Rio De Janeiro city of Brazil under the aegis of United Nations for the protection of the earth and its environment, maintenance of ecological balance and to enrich biodiversity. The conference was attended by the representatives of 178 developed and developing countries. The primary objectives of the conference were to arrive at commonly acceptable agreements and their implementation to tackle the problems of global warming, depletion of ozone layer and. ozone hole, deforestation, biodiversity, weather and climate change, acid rain, sustainable development etc. The following were five important agenda of the conference--(i) Rise in global temperature (global warming), (2) forest protection (3) biodiversity, (4) agenda 21, and (5) Rio declaration. Only two aspects of global warming and forest conservation of Rio Summit are being discussed here as only these two are directly concerned with global warming and climate change.

(i) Global Warming

A rise of 1.5°C in the atmospheric temperature has been reported for the last 75 years (upto 1995). Some sources put this rise from 0.3°C to 0.6°C. Greenhouse gases (carbon dioxide, methane, chlorofluorocarbon, nitrous oxide etc.) have been identified as major factors of global warming. It is, thus, apparent that the global warming is due to anthropogenic economic activities. Greenhouse gases are emitted from industrial establishments, automobiles, domestic appliances etc. and these gases are concentrated in the lower atmosphere, and thereafter they increase air temperature. The relative shares of carbon dioxide, chlorofluorocarbon, methane and nitrous oxide were 51%, 20%, 16% and 16% respectively up to 1990. It may be pointed out that

developed countries are themselves responsible for ozone depletion and depletion and creation of ozone hole.

(ii) Forest Conservation

At the time of earth summit all the participants expressed deep concern and anger at the rapacious and reckless cutting of forests. It may he pointed out that according to an estimate about 8,000 years ago 8,000 million hectares of land were covered With forests which decreased to 3,000 million hectares by 1998. 1ndia is losing its forest cover at the rate of 2.8 per cent per year. It may be noted that the developed countries have already consumed major portions of their forest covers. It may be underlined that the tropical rainforests are richest in biodiversity and have medicinal importance.

(iii) Second Earth Summit

The second earth summit was held from June 23 to 27, 1997 in New York city of the U.S.A. in order to evaluate the progress and implementation of proposals and Agenda 21 which were agreed during the First Earth Summit organized in 1992 in Rio De Janeiro city of Brazil. The second earth summit was attended by representatives of 170 countries with 70 heads of government. This summit is also known as Plus-5 Summit because this summit was organized after 5 years from the second earth summit (Rio Summit) and the programmes and action plans (accepted during Rio Summit) were discussed and reviewed but -ultimately no concrete and fruitful results could be achieved because no agreement could be made on any agenda. Various agenda which were endorsed during Rio Summit e.g. financial help for check on global rise in temperature, effective cut in the emission of greenhouse gases, law of forest conservation, sustainable agricultural development, conservation of biodiversity, eradication of Poverty etc. could not be sincerely implemented.

(iv) Kyoto Protocol

A summit to reduce global warming was held from December 1 to 10,1997 in Kyoto city of Japan and an agreement to this effect was also signed. This summit was attended by the representatives of 149 countries. This agreement is popularly known as **Kyoto Protocol** or **Kyoto Thermal Treaty**. The following are the main items of this historic agreement:

- A proposal of 30 per cent cut in the emission of carbon dioxide by 2008-12 A.D. was presented by the island nations on the fear that the temperature is estimated to rise 2°C to 3.5°C at the present rate (1997 level) of global

warming but the proposal was strongly opposed by the developed and industrialized countries.

- According to this agreement industrial countries can have mutual transfer of fixed quota of cut in the emission of greenhouse gases.
- The Kyoto Protocol and agreement would automatically be invalidated if at least 60 countries of conference of Parties (CoP) do not endorse and implement its provisions and resolutions. The protocol was to be effective from June, 1999. A fine would be imposed on those countries which do not adopt the protocol.
- A Clean Development Fund (CDP) would be established which would be funded by the fines realized from the countries which flout the protocol.

Review of Kyoto Protocol : One positive outcome of the Kyoto Conference on Climate Change and Kyoto Protocol is that the developed and developing countries accepted at least in principle that some concrete steps should be initiated to check climatic change due to rise in global temperature. The developing and poor countries succeeded in managing unanimity on the point that reduction in the emission of greenhouse erases would not be binding on them. It may be pointed out that the emission of greenhouse gases from a few big developing countries like China, India, Brazil etc. would also increase substantially in near future.

(v) Carbon trading

As per Kyoto Protocol carbon trading simply means a that in order to implement the mandatory cut in the overall carbon emission by at least 5 per cent below 1990 level between 2008- 2012 A.D. the industrialized developed 'countries and their private corporations could invest in projects in developing countries which are carbon efficient. The net benefits of carbon reduction would accrue to the industrialized country or private corporation in its balance sheet of carbon accounting. Developing countries would be selling `**certified emission reduction" units'** (Down to Earth, July 31, 1998). It is proposed to set up a global Executive Board (EB) to supervise carbon trading and numerous certification agencies will authorized by the Executive Board. Several organization and establishments have floated various brokers for managing carbon trading. For example, Carbon Investment Fund by the World Bank, Portfolio of projects of interest by the Asian Development Bank, Emission Trading Corporation by the United Nations Conference on Trade and Development (UNCTAD).

9.10 Causes and Theories of Climatic Changes

Climatic changes are affected by changes in atmospheric circulation and interactions among five components of the earth-atmosphere system, namely atmosphere, hydrosphere, lithosphere, biosphere and cryosphere (frozen surface of the earth) wherein the amount of received solar energy, and the process of distribution, redistribution, and absorption of solar radiant energy at the earth surface are important considerations of the state of climate of an area in specific time period. The causes for such interactions leading to climatic changes are related to (I) outside sources, say extraterrestrial sources, and (2) inside sources, say earth-atmosphere system or terrestrial sources.

The causes and theories of climatic changes are viewed in terms of periodicity of climatic changes which are generally of two types, namely (I) short-term climatic changes and (2) long term climatic changes. Since the nature and patterns of climatic changes vary temporally and hence the causes of such changes are also of varied nature. This is why no single theory can explain all types and patterns of climatic changes and thus we have a host of causes and theories of climatic changes. Since the Industrial Revolution (1860 A.D.) the man's increased economic activities and the application of advance technologies are introducing significant modifications and changes in climatic conditions. Thus, the sources of climatic changes may be grouped in the following 3 broad categories:

(1) Outside of extra-terrestrial sources

(2) Inside or terrestrial sources

(3) Anthropogenic sources

The significant causes and related theories of climatic changes may be stated as follows:

(1) Solar irradiance theory (variation in solar radiation),

(2) Sunspot cycles,

(3) Astronomical theories

(4) Atmospheric dust hypothesis (mainly volcanic eruptions and dusts thereof)

(5) Carbon dioxide hypothesis,

(6) Continental drift and pole wandering,

(7) Tectonic and topographic control theory,

(8) Oceanic variation hypothesis,

(9) Extra terrestrial bodies collision theory,

(10) Anthropogenic sources (changes in the earth's surface and atmospheric composition).

1) **Solar Irradiance Theory:** Solar radioactive forcing is considered to be a significant factor of climatic changes- it is important to note that there are fluctuations in the energy radiated from the sun's outer surface (photosphere).. It may also be mentioned that the amount of solar energy received at the earth' s surface determines the nature and pattern of energy exchanges and atmospheric circulations which in turn determine temperatures and precipitation. The amount of solar radiant energy received at the earth's surface is also subject to changes due to (i) changes in the composition of the atmosphere in terms of its transparency to incoming shortwave solar electromagnetic radiation waves, (2) changes in the relative distances between the sun and the earth, (3) the amount of the energy radiated from the earth's surface, (4) changes in the surface covers of the earth's surface etc. The variations in solar irradiance are viewed as (i) long-term change, and (ii) as short-term or periodic change (Le. sunspots cycles). It is a common belief that increase in solar radiation for longer duration will cause warming of the atmosphere leading to onset of warm climate and melting of ice sheets and glaciers.

2) **Simpson Theory:** Sir George Simpson presented an entirely different concept related to variations in solar radiation and climatic changes in 1938 A.D. According to the Simpson during the period of moderate increase in solar irradiance, the middle and high latitudes will experience extension in glaciers and their advances while decrease in solar radiation and resultant decrease in air temperature would cause melting of ice sheets and glaciers and their retreat , resulting into onset of interglacial period. Simpson propounded the concept of cyclic pattern of increase and decrease in solar radiation. According to him the atmospheric temperature increases with increase in solar radiation. The increase in atmospheric temperature causes increase in evaporation and cloudiness, strong meridional air circulation and increased precipitation in higher latitudes. The precipitation in higher latitudes is in the form of snowfall which allows more accumulation of ice and extension of ice sheets and glaciers. The greater cloudiness during summer season prohibits melting of accumulated snow and ice

rather protects the ice cover. On the other hand, during the phase of decrease in solar radiation, the atmospheric temperature decreases, meridional air circulation is weakened, evaporation and precipitation remarkably 'decreases in high latitudes, melting of ice sheets causes their retreat. 'Thus, paradoxically a lowering of mean atmospheric temperature might cause a recession of ice sheets, whereas temperature increase would lead to their advance. Although the Simpson theory appears not to fit recent instrumental evidence, it is a warning against oversimplified explanations of complex processes (H. J. Critchfield, 2002).

3) **Sunspot Theory**: The sunspot activity has been related to variations in solar irradiance. The increased sun-spot activity (increase in the number of sunspots) causes warming of the earth's surface and its atmosphere whereas decreased sunspot activity (decrease in the number of sunspots) causes lowering of atmospheric temperature. Sunspots are darker and cooler areas in the photosphere of the sun. The increased sunspot activity means increase in the number of sunspots while decreased sunspot activity is related to decrease in the number of sunspots. The study of sunspot activity for the last 200 years has revealed cyclic pattern of increase and decrease in sunspot activity. On an average, 11 years cycle has been accepted where as the period of one cycle may be as short as 8-9 years and as long as 16 years. The prolonged period of minimum sunspot activity, called as **Maunder Minimum**, is supposed to introduce cooling of the earth surface and its atmosphere, whereas the period of maximum sunspot activity cause warming,. It may be mentioned that correlation between sunspot activity and atmospheric temperature has not been substantiated.

4) **Atmospheric Dust Hypothesis:** The atmospheric solid particulate matters include dust particles, salt particles, pollen, smoke and soot, volcanic dusts and ashes etc. Most of the solid particles are kept in suspension in the atmosphere. It is an established fact that these solid particulate matters (SPM) present in the atmosphere reduce the amount of solar radiant energy reaching the earth's surface by scattering, reflection and absorption of incoming shortwave electro-magnetic solar radiation. About 23 per cent of incoming solar radiation is scattered by dust particles and haze. of which 6 per cent energy is sent back to the space while 17 per cent energy reaches the earth's surface as diffuse day light, of course much later. The scattering of incoming solar radiation waves by dust particles when the

diameter of such particles is longer than the wavelengths of incoming solar radiation waves, is called diffuse reflection which sends some portion of incoming solar energy back to space while some portion remains in the lower atmosphere.

It is also an established fact that sudden increase in dust particles caused by violent powerful volcanic eruptions reduces the tempera-and climatic conditions at least at shorter temporal here lure of the earth's surface at. its lower atmosphere remarkably and introduces fluctuations in weather scale, It may be remembered that the stratospheric temperature increases at the time of greater volcanic activity because most of the scattered, reflected and absorbed energy remain there, but the temperature of the lower troposphere and the earth's surface drops significant, and it is the temperature of the lower atmosphere that controls weather and climate at the earth's surface. This corollary may and resultant be substantiated with a few examples of volcanic eruptions cooling of the earth's surface and its atmosphere.

5) **Carbon Dioxide Theory:** It is important to note that it is the receipt of solar energy at the earth's surface and absorption of incoming solar radiation and outgoing terrestrial radiation by the atmosphere which has significant control on weather and climate, and the amount of energy received at the earth's surface depends on (1) changes in the composition of the atmosphere (2) changes in the transparency of the atmosphere, (3) modification of energy in the transit (i.e. flowing through the atmosphere) etc. The changes in the gaseous composition of the atmosphere are effected by both natural and anthropogenic sources. The increase of relative proportion of greenhouse gases (e.g. carbon dioxide, methane, nitrogen oxides etc.) in general and carbon dioxide in particular causes global warming and initiates warm climate while decrease in their relative percentage causes global cooling and helps in initiating cold climate if other factors remain constant. Thus, the carbon dioxide theory states that increase and decrease in temperatures of the earth's surface and its atmosphere is affected by increase and decrease of its (CO_2) relative percentage in the gaseous composition of the atmosphere respectively. It may be remembered that the increase of earth's temperature by absorbing outgoing terrestrial infrared radiation by certain gases (mainly carbon dioxide) is called **greenhouse phase of the atmosphere** whereas **icehouse phase** refers to lowering of earth's temperature leading to beginning of glacial

period. The **greenhouse effect** means "Progressive warming up of the earth's surface due to the blanketing effect of man -made carbon dioxide in the atmosphere'. In a green house, visible sunlight passes through the glass and heats up the soil warming the plants. The warm soil emits radiation in longer wavelengths particularly in the infrared band. Because the glass is opaque to these wavelengths, it absorbs and reflects the infrared. This mechanism keeps the greenhouse warmer than the outside environment. Different models have been developed to reveal the relationships between the increase in tin concentration of atmospheric carbon dioxide through anthropogenic sources and climate changes but the predictions of these models are very much confusing and contradictory. 'if there is uncertainty in the prediction of carbon dioxide trends, then the predictions of the resulting, climatic effects are even more uncertain (J. E. Hobbs, 1980).

6) **Schneider Model. (1950)**: S.H. Schneider while reviewing the results of -various climatic models dealing with the predictions in the change of thermal conditions of the atmosphere and the earth's surface resulting from the increased content of atmospheric carbon dioxide concluded that the temperature could rise upto 1.5C-3.0°C if the concentration of atmospheric carbon dioxide could be doubled from 300 ppmv level to 600 ppmv. He further predicts that increased temperature would cause increase in evaporation and cloudiness which would reduce incoming solar radiation (because of increased albedo i.e. more clouds would reflect more solar radiation back to space). Thus, the reduced solar radiation reaching the earth's surface would counteract the warning of the earth's surface. It is obvious that such feedback mechanisms negate the impact of green-house effect of increased atmospheric carbon dioxide and the whole process of the heating or cooling of the lower atmosphere and the earth's surface becomes complicated. Another model envisages cooling of the earth's surface due to enormous increase in the atmospheric carbon dioxide.

7) **General Circulation Model (GCNI):** The general circulation model by S. Manabe and R.T. Wetherald (1975) predicts that if present amount (1975 level) of carbon dioxide of the atmosphere is doubled, the temperature of the earth's surface will increase by 2.9°C and there will be 7 per cent increase in the activity of hydrological cycle but there will not be any feedback and thus there will not be either increase or decrease in the amount of cloudiness.

8) **Atmospheric Oceanic General Circulation Model (AOGCM);** As per the report of the Intergovernmental Panel on Climate Change (IPCC, 2001). If the concentration of atmospheric CO_2 increases to 540-970 ppmv by the end of the 21 st century, the average surface air temperature at global level would register an increase between 1^0C to 5.8^0C. This increase in average air temperature has been estimated in relation to average air temperature during 1990-2000 A.D. The trends of probable future future climatic change due to increase in average surface air temperature at global level have been estimated on the basis of increase in the concentration of greenhouse gases in the atmosphere in future.

9) **Astronomical theories:** Climate change is a global environmental problem which has been receiving intense political attention both at domestic and international levels. The United Nations Framework Convention on Climate Change (UNFCCC) defines 'climate change' as a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods. The major characteristics of climate change include rise in average global temperature, ice cap melting, changes in precipitation, and increase in ocean temperature leading to sea level rise. The efforts needed to address the climate change problem include mitigation of GHG emissions on one hand, and building of adaptive capacities on the other in developing countries to cope with the adverse impacts of climate change on various sectors of the society and economy enabled and supported by technology and finance. Important negotiations and conventions related to climate changes are given in Table.1

Table.1 Conventions and negotiations on Climate Change:

The first World Climate Conference (WCC)	1979
The Intergovernmental Panel on Climate Change is set up	1988
IPCC's first assessment report released. IPCC and second World Climate Conference call for a global treaty on climate change. United Nations General Assembly negotiations on a framework convention begin.	1990
First meeting of the Intergovernmental Negotiating Committee (INC) takes place.	1991
The INC adopts UNFCCC text. At the Earth Summit in Rio, the UNFCCC is opened for signature along with its sister Rio Conventions, UNCBD and UNCCD.	1992
UNFCCC enters into force.	1994
The first Conference of the Parties (COP 1) takes place in Berlin	1995
The UNFCCC Secretariat is set up to support action under the Convention	1996
Kyoto Protocol formally adopted in December at COP3	1997
Release of IPCC's Third Assessment Report.	2001
Entry into force of the Kyoto Protocol. The first Meeting of the Parties to the Kyoto	2005

Protocol (MOP 1) takes place in Montreal.	
IPCC's Fourth Assessment Report released. Climate science entered into popular consciousness.	2007
Copenhagen Accord drafted at COP15 in Copenhagen. This was taken note of by the COP. Countries later submitted emissions reductions pledges or mitigation action pledges, all non-binding.	2009
Cancun Agreements drafted and largely accepted by the COP, at COP16	2010
The Durban Platform for Enhanced Action drafted and accepted by the COP, at COP17	2011

Climate change may pose a threat to food security through erratic rainfall patterns and decreasing crop yields, contributing to increased hunger and malnutrition in India. Furthermore, adverse climate change impacts on natural systems and resources, infrastructure, and labour productivity may lead to reduced economic growth and increasing poverty. These effects threaten the achievement of MDG 1. Loss of livelihood assets, displacement and migration may lead to reduced access to education opportunities, thus hampering the realization of MDG 2. Depletion of natural resources and decreasing agricultural productivity may place additional burdens on women's health and reduce time for decision-making processes and income-generating activities, worsening gender equality and women's' empowerment (MDG 3). Increased incidence of vector-borne diseases, increases in heat-related mortality, and declining quantity and quality of drinking water will lead to adverse health effects threatening the achievement of MDGs 4, 5, 6 and 7. In general terms, the realization of MDG 7 may be approached through climate change negatively impacting quality and productivity of natural resources and ecosystems, possibly irreversibly, threatening environmental sustainability. Climate change, a global phenomenon, calls for a collective response in the form of global partnerships (MDG 8).

9.11 Mitigation and Adaptation

Anticipating the negative effects of climate change and acting appropriately to prevent or minimize the harm they can bring, or seizing opportunities that may present themselves, is what is meant by adaptation. Examples of adaptation strategies include extensive infrastructure modifications, such as the construction of sea level rise fortifications, as well as behavioral changes, such as people cutting back on food waste. The process of adjusting to the present and future effects of climate change can be viewed as the essence of adaptation.

By preventing or limiting the production of greenhouse gases (GHG) into the atmosphere, **mitigation** refers to lessening the severity of the effects of climate change. Mitigation can be accomplished by either reducing the sources of these gases, such as by increasing the proportion of renewable energies or implementing a cleaner transportation system, or by improving the storage of these gases, such as by expanding forests. In a nutshell, mitigation refers to human action that lowers GHG emission sources and/or improves sinks.

We must prepare for the change that is now here and will continue to affect us for the foreseeable future because mitigation measures will take decades to have an impact on rising temperatures. Mitigation may prompt a range of policy discussions and actions. In a recent survey of land trusts, 60% of respondents said they were building awareness or incorporating climate change into their conservation efforts. By considering the impacts of climate change in their normal land conservation activities, land trusts can provide strategic investments and effective land management to help reduce the vulnerability of natural areas, working lands, and the human communities that depend on them. Mitigation case studies highlight how some land trusts are encouraging mitigation through land use interventions as well as leading by example to adopt green energy technologies and support sustainable growth policies.

Mitigation through Land Use Interventions: As stewards of the land, conservation organizations can play a unique role to encourage and practice climate change mitigation. From engaging in regional planning, like the Jefferson Land Trust, to actively acquiring critical properties slated for development, as the Hawaiian Islands Land Trust did with their Waihe'e Coastal Dunes and Wetlands Refuge, land trusts are developing expertise to facilitate less carbon-intensive land uses by effectively influencing land use planning processes. Some groups, such as the Vermont Land Trust, structure their agricultural conservation easements to allow the use of small-scale renewable energy technology and infrastructure, which can mitigate greenhouse gas emissions as well as offer an example of good stewardship practices that may inspire other community members. Other groups, such as the Downeast Lakes Land Trust, Pacific Forest Trust, and The Conservation Fund, have identified and implemented opportunities for carbon projects that avoid or offset greenhouse gas emissions in concert with other management objectives.

Mitigation by Example – Conservation Leadership at Work: By planning for climate change, your land trust is already making a positive impact in your community. You can extend that reach by connecting with your audience, raising their awareness and inspiring action to reduce emissions and thus the impacts of climate change.

By raising awareness and calling for individual and community climate action, land trusts can play a critical role in guiding future land use planning in their region. Ultimately, land trusts may be able to help shape climate change policy, reduce community-wide carbon footprints and enhance the resilience of natural and developed environments to climate change impacts.

- Inspiring climate change action in your community involves three steps:
- Raise awareness of climate change, and how it affects the things your audience cares about.
- Engage your community through publications and programs.
- Launch climate action projects in your community.

9.11.1 Adaptation and Mitigation strategies

Both mitigation and adaptation are needed to significantly reduce the risks and increase the resilience of the world's most vulnerable citizens. In the near term, adaptation actions can reduce the impacts of climate change (although they cannot be reduced to zero). In the longer term, a failure to mitigate climate change will lead to such massive impacts that adaptations will be unsuccessful. Mitigation means taking action to reduce greenhouse gas emissions to avoid further climate change than has already occurred due to historic and current emissions. It is about transforming the way that individuals, governments and industry produce and use energy, changing activities to reduce or eliminate emissions, and developing clean and efficient infrastructure where it does not currently exist. Adaptation and mitigation should not be considered as either/or strategies, but rather as complementary ones that should be pursued together.

Some of the major schemes/policies significantly addressing adaptation objectives are as follows:

- ✓ Mahatma Gandhi Swarnajayanti Gram Swarozgar Yojana (Rural self-employment program)

- ✓ Sampoorna Grameen Rozgar Yojana (Comprehensive rural employment scheme)
- ✓ Pradhan Mantri Gram Sadak Yojana (Prime Minister's rural roads program)
- ✓ National Rural Health Mission
- ✓ Accelerated Rural Water Supply Programme
- ✓ Desert Development Programme
- ✓ Major and Medium Irrigation
- ✓ Sustainability of Dryland/ Rainfed Farming System and
- ✓ Disaster Management

Eight key interventions may be identified that will contribute to reductions in human security risks and health vulnerability among the people.

(i) Household water supply, sanitation and hygiene- including water treatment, oral rehydration therapy, hygiene education and sanitation.

(ii) Groundwater recharge and watershed remediation- including rainwater harvesting, run-off catchments, watershed clean-ups, tree planting and restoration of biodiversity.

(iii) Disaster risk reduction and preparedness- including risk mapping and evacuation plans.

(iv) Environmental protection and restoration- such as school and community gardens, tree planting and clean up of stagnant water and solid waste.

(v) Renewable energy solutions- including clean energy for homes, communities, solar and wind water pumps and clean and efficient household solutions for cooking and heating.

(vi) Health-related interventions- including improvements to basic public health infrastructure, environmental health surveillance, insecticide-treated mosquito nets and malaria prophylaxis and treatment.

(vii) Community capacity-building- including environmental education, micro enterprise for women, education for sustainable development, participatory local actions and vocational training/job creation.

(viii) Social protection and psychosocial support- including life skills and conflict resolution, education and other programmes to support livelihoods and community functioning, 'safety net' interventions to help prevent dislocation

and exploitation of children, and interventions to address family and individual stress and trauma.

9.11.2 Measures for Mitigating Climate change

The important measures for mitigating climate change are as follows:

1) Improving energy efficiency and conservation as well setting up a Bureau of Energy Efficiency
2) Power sector reforms
3) Promoting hydro and renewable energy
4) Promotion of clean coal technologies
5) Coal washing and efficient utilization of coal
6) Afforestation and conservation of forests
7) Reduction of gas flaring
8) Cleaner and lesser carbon intensive fuel for transport
9) Encouraging Mass Rapid Transport systems
10) Environmental quality management and improving energy efficiency

Below are five solutions that can both curb climate change and help us cope with its impacts at the same time:

1. Protect Coastal Wetlands: Mangroves, seagrass, and salt marshes are distinctive coastal ecosystems that act as marine habitats and natural water filters. By absorbing storm surges and floodwaters, they protect coastlines from sea level rise. They also store massive amounts of carbon in the soil and roots of their plants. Mangrove forests presently store more than two years' worth of global emissions, which, if these forests were to be destroyed, would be released into the atmosphere and exacerbate the consequences of climate change. By 2050, it is possible to reduce one gigaton of CO2 annually, or more than three years' worth of emissions, by increasing protected coastal wetlands and recovering roughly 40% of the ecosystem's global coverage. Local communities that depend on these ecosystems for their homes and means of subsistence must be included in efforts to preserve coastal wetlands. To manage these wetlands and aid in the development of neighboring communities, nations like Fiji and Papua New Guinea have had success with community-based conservation and education.

2. By Promoting the Benefits of Sustainable Agroforestry: It is obvious that the current land management practices need to alter because land use changes from forestry and agriculture contribute for almost 25% of anthropogenic greenhouse gas emissions. Agro forestry techniques combine various trees or shrubs with animals and crops. For example, compared to treeless regions of the same size, pastures with trees can trap five to ten times more carbon. By simultaneously raising cattle and growing crops, farmers may increase their productivity while using much less area. Farmers can increase their sources of income and lessen the dangers to their livelihoods posed by climate change and unpredictable weather by diversifying their crops and keeping livestock on these sites.

3. Decentralize the Distribution of Energy: Infrastructure for electricity transmission and distribution will be significantly impacted by climate change. The demand for and use of energy are both rising concurrently with development and population expansion. Since interruptions at one point in the system can have an impact on the entire network, centralized energy systems with huge power plants and infrastructure connecting across long distances are particularly sensitive to climate change. Power sources that are smaller and easier to control can also recover from disasters more quickly. Hospitals in distant places without grid access or who frequently face power outages can receive dependable, clean energy from low-carbon solutions like solar panels and batteries.

4. Protect the land rights of indigenous peoples: Around 2.5 billion people rely on the nearly 50% of the planet's land that is managed by indigenous and local populations for their livelihoods. As a result of these communities' generations-long application of adaptation principles on their lands, they have amassed a rich corpus of folk wisdom that may instruct others on how to adjust to changing environmental conditions. Additionally, as demonstrated in Bolivia, Brazil, and Colombia, areas where indigenous people have secure tenure over their property experience at least a two-fold reduction in deforestation compared to comparable areas without such rights. A quarter of the above-ground carbon in tropical forests is stored in woods that indigenous people and local communities have preserved. Yet less than a quarter of this land is really legally owned by these groups. The protection of indigenous peoples'

rights will enable them to maintain their rights to their land, save the environment, and better maintain their way of life in the face of climate change.

5. Strengthen Public Transit: In the absence of more affordable and accessible low-carbon transportation options, road transport now contributes 72% of all emissions connected to transportation in the world. Storms and high temperatures are only two examples of how climate change will affect transportation infrastructure. Extreme weather-related network outages will disproportionately affect low-income individuals and other vulnerable urban populations who have fewer transportation options. Both issues are addressed by resilient, low-carbon public transportation. By 2050, urban public transit may be increased by 40%, which would reduce the number of cars on the road and prevent 6.6 gigatons of carbon emissions. Mass transit may be made safe and reliable by being retrofitted and designed to withstand climate hazards such natural catastrophes, sea level rise, and excessive heat.

6. Prioritizing multidimensional climate solutions: These are only a few instances of climate measures that simultaneously address adaptation and mitigation. There are numerous others that can accommodate various industries, ecosystems, nations, and communities. The urgent and severe climate problem, the necessity for such coordinated efforts must be prioritized by policymakers due to the limited budget, resources, and attention that can be given to fixing the problem.

The international community became alive to climate change and its likely impact on the plant and humans especially in the late twentieth century. Accordingly, various efforts were made to contain, combat and mitigate the effects of climate change. These can be broadly discussed under the following heads:

(i) Montreal Protocol to Vienna Convention

(ii) Setting up of IPCC

(iii) Adoption of UNFCCC

(i) Montreal Protocol to Vienna Convention

Vienna Convention for the protection of ozone layer was signed in 1985. The Convention was the result of the efforts of the world community to protect ozone layer when a huge hole was detected in it over Antarctica. Vienna Convention was aimed at

promoting cooperation among nations regarding the depletion of ozone layer and to promote research and information exchange on the impact of human activities on ozone layer. However, the Convention was not a binding document and it provided for adoption of Protocols of binding nature for reducing the emission of Ozone Depleting Substances (ODS). To have a legally binding instrument, Montreal Protocol to Vienna Convention was adopted in 1987 which is a supplementary agreement to the Protocol. Montreal Protocol aimed at controlling and curbing global emission of substances that deplete the Ozone layer or modify the Ozone Layer and ultimately elimination of ODS. Though originally the Protocol was adopted to protect the Ozone Layer yet the potential effects of emission of ODS on climate change have been recognized since ODS are also potent greenhouse gases and contribute significantly to climate change. So far Protocol has been amended six times i.e. London Amendment, 1990; Copenhagen, 1992; Vienna Accord, 1995; Montreal Amendment, 1997; Beijing Amendment, 1999 and; Kigali Amendment, 2016. These amendments have added list of controlled substances which are required to be phased out for protection of Ozone layer. Kigali amendment added HFC's as a controlled substance and provided schedule for reduction of use of HFCs by 80-85%. HFC phasing out is expected to prevent 105 million tonnes of carbon dioxide equivalent of greenhouse gases and will help to avoid 0.5 degree temperature rise by 2100 (UNEP).

(ii) Intergovernmental Panel on Climate Change (IPCC)

IPCC was set up in 1988 by World Meteorological Organization and United Nations Environment Programme (UNEP) with the following objectives:

- ✓ To assess climate change, the scientific basis of climate change and submit reports thereon so that governments can take steps and frame policies to deal with climate change on scientific basis
- ✓ To study the effects of Climate Change
- ✓ To study and analyse future risks associated with climate change and
- ✓ Develop a suitable approach to combat, mitigate and adapt to climate change

Since its establishment IPCC has completed five assessment cycles and is currently in sixth assessment cycle. IPCC assessments are authored by select leading scientists and the reports are meticulously drafted, reviewed and finalized to provide factsheet and scientific data. It has established three working groups on the following basis

- ✓ Physical Science Basis
- ✓ Impacts Adaptation and Vulnerability
- ✓ Mitigation of Climate Change

(iii) United Nations Framework Convention on Climate Change (UNFCCC)

UNFCCC is an intergovernmental treaty which has been entered into for coping up with the issue of climate change and it provides a framework for dealing with climate change. UNFCCC was opened for signature in Rio Earth Summit in June 1992 i.e. in United Nations Conference on Environment and Development (UNCED) and it entered into force on 21st March 1994. The main aim of UNFCCC is to stabilize greenhouse gas concentration in a time bound manner so as to reduce and contain the impact of GHG on climate change. UNFCCC recognizes and is based on the Doctrine of 'Common but Differentiated Responsibilities and respective capabilities'. This principle takes into account that the damage to environment and climate as a result of emission of GHG is caused primarily by developed nations since their emission levels and per capita emissions are much higher than developing countries but the adverse impact of the emission of GHG is on the entire community.

Therefore, it is the common responsibility of all nations to reduce the emission of GHG but at the same time it recognizes special needs of developing and least developed countries to develop and therefore, it is recognized that their level of emission of GHG is likely to increase yet and they are also likely to cause damage to environment and contribute to climate change. The onus is cast on Developed countries which are detailed in Annex A to reduce emission of GHG and also to help developed and developing countries in containing GHG by technology transfer and financial support. UNFCCC mandates preparation of annual inventory of GHG emissions including data for base year (1990). It is worth mentioning here that initially the thrust of UNFCCC was on mitigating the climate change and therefore to contain the emission of GHG. However, after the adoption of Cancun Adaptation Framework (CAF) at Cancun Climate Change Conference, 2010, the focus on adaptation to climate change has also been made. The purpose of CAF is to accord same level of priority to adaptation as is given to mitigation and accordingly to prepare the developing countries to adapt to climate change so as to reduce their vulnerability.

Kyoto Protocol: UNFCCC provided for a framework to deal with climate change. Immediately after adoption of UNFCCC and its entry into force in 1994, it was felt that

UNFCCC should be further strengthened by enacting a Protocol which should lay down mandatory targets for reduction of GHG emissions and accordingly, negotiations began to enter into a Protocol. The negotiations resulted in adoption of Kyoto Protocol in December 1997 in Kyoto, Japan. The Protocol entered into force on 16th February 2005. The Protocol has provided mandatory targets for reduction of GHG emissions by Annex 1 countries i.e. developed countries and countries with economies in transition to market economy. The object of the Protocol was to reduce emission of GHG by atleast 5% below 1990 levels during the first commitment period i.e. 2008-2012. The Protocol was based on CBDR and therefore the targets were different for different countries like the target was 8% for European Union, 6% for Canada, 7% for USA and 6% for countries like Hungry, Japan, Poland, New Zealand, Russia, Ukraine etc. Higher targets have been prescribed for second commitment period i.e. for 2013 to 2020 e.g. European Union has agreed to have joint target of 20% reduction of GHG of its 1990 level. The Protocol offers flexibility to the nations to reduce emissions in their own territory or to finance projects in other countries to reduce emissions. Further, the emission targets can be compensated by increasing sinks of carbon dioxide. Oceans and forests are the sinks of carbon dioxide therefore increasing forest cover can reduce increased carbon dioxide from the atmosphere. Protocol has also established Clean Development Mechanism (CDM) which allows flexibility to developed countries to achieve their emission reduction targets by sponsoring emission reduction projects in developing countries and earning saleable Certified Emission Reduction (CER) credits which can be used to achieve reduction targets.

Paris Agreement: Much celebrated Paris Agreement under UNFCCC was entered into in 2015 in 21st Conference of Parties of UNFCCC. The Paris Agreement is viewed as a major breakthrough in climate change efforts wherein the countries of the world came together and agreed for reduction in emissions so as to limit increase in global average temperature upto 2 degree Celsius above pre-industrial levels. The ambitious aim of the Paris Agreement is to contain temperature increase upto 1.5 degree Celsius above pre-industrial levels. Paris Agreement, being entered into under the Framework Convention, also recognized and applied principle of CBDR and therefore, it recognizes that the emissions of developing countries and least developed countries are yet to peak to meet their developmental needs. Therefore, the agreement desires that the global emissions of GHG should peak as early as possible and there should be

rapid reductions thereafter. The Agreements calls for ensuring that the global emission of GHG during the period 2050 to 2100 should be to that level only which can be absorbed by natural sinks. Agreement mandated parties to submit Intended National Determined Contributions (INDC) containing the action plan of the country parties to contain climate change and to reduce the emission of GHG. Agreement provides for revisions of targets periodically i.e. every five years. Like the CAF, it also stresses 'adaptation' strategies so as to adapt to climate change to reduce the vulnerability to the adverse impacts of climate change.

Climate Change Change Performance Index (CCPI): After briefly discussing climate change, its effects, and the global initiatives to fight it, reduce its effects, and adapt to it as a result of human activity. It is important to consider how various nations are performing in this area. Since 2006, German watch and the Climate Action Network, Europe have released an annual Climate Change Performance Index. They have been keeping an eye on the activities of the nations that emit 90% of the greenhouse gases for the past thirteen years. The fundamental objective of the CCPI is to increase accountability in global climate policies and make it possible to compare the climate protection initiatives of signatory countries in order to highlight successes and failures. The CCPI uses 14 metrics to assess each nation's performance across four categories (Figure 4):

- ✓ Greenhouse gas emissions account for 40% of the overall rating,
- ✓ Renewable energy makes up 20%.
- ✓ Use of energy: 20%
- ✓ 20% for climate policy
- ✓ According to the CCPI 2022 study, Denmark receives a "High" rating (Fourth ranking) in the categories of greenhouse gas emissions, renewable energy, and climate policy. SWEDEN (5th), NORWAY (6th), THE UNITED KINGDOM (7th), MOROCCO (8th), CHILE (9th), AND INDIA (10 th) are the top-ranked nations overall. The top three rankings are unfilled because no country has received the highest rating according to the CCPI categories (Figure 5).

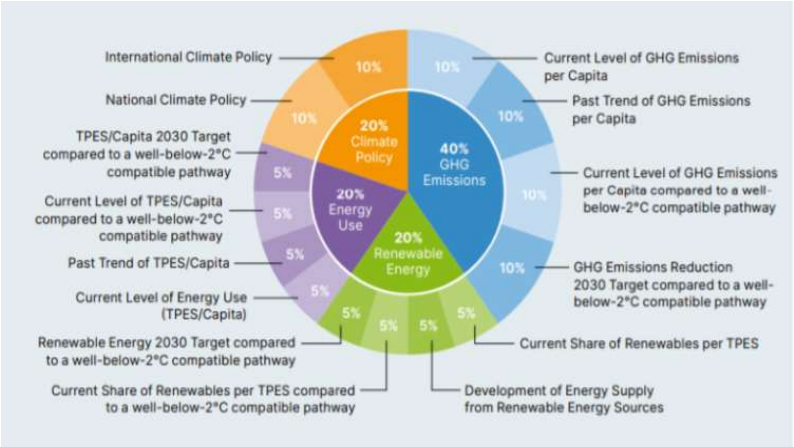
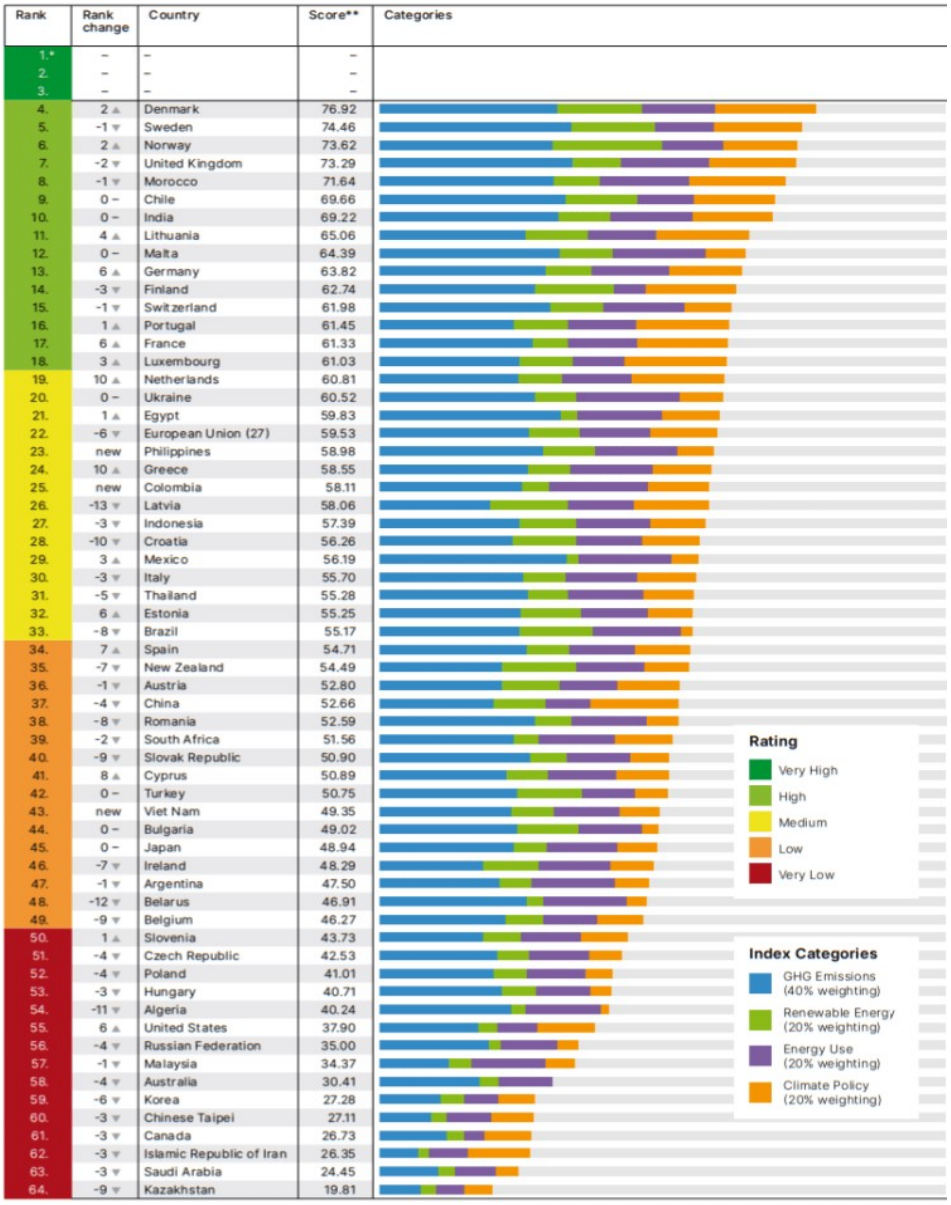


Figure 4. CCPI Categories and it's 14 Indicators that are used for country rating
Source: https://pcsstudies.com/climate-change-performance-index-ccpi-2022/

With a score of 69.22 out of 100, INDIA has maintained its position as one of the top 10 best-performing nations for the last three years. India's performance was rated HIGH in the categories of "Greenhouse Gas (GHG) Emission, Energy Use, and Climate Policy," and MEDIUM in renewable energy.

- ✓ No country this year achieved the highest ranking in the CCPI performance categories; hence the top three spots were once again vacant.
- ✓ Denmark has the highest rating and is ranked fourth in the CCPI 2022, even though it hasn't done well enough overall to get such a high grade.
- ✓ G20 Countries: According to the report, the UK is the G20's top performer, followed by India (10th), Germany (13th), and France (17th). Eleven nations were given an overall ranking of Low or Very Low.
- ✓ The G20 nations account for over 75% of global greenhouse gas (GHG) emissions.
- ✓ Saudi Arabia is placed 63rd overall and the G20's worst performing nation.
- ✓ According to the CPPI report for 2022, Australia is the least performing country, having dropped 4 spots to rank 58th. Look Australia has consistently performed poorly and received very low ratings across all CCPI rating categories going all the way back to CCPI 2014.
- ✓ According to the CCPI, the bottom 10 low-performing nations are Algeria (ranked 54), the United States (ranked 55), the Russian Federation (ranked 56), Malaysia (ranked 57), Australia (ranked 58), Korea (ranked 59), Chinese Taipei

(ranked 60), Canada (ranked 61), the Islamic Republic of Iran (ranked 62), Saudi Arabia (ranked 63), and Kazakhstan (64th).



Rank	Rank change	Country	Score**
1.*	–	–	–
2.	–	–	–
3.	–	–	–
4.	2 ▲	Denmark	76.92
5.	-1 ▼	Sweden	74.46
6.	2 ▲	Norway	73.62
7.	-2 ▼	United Kingdom	73.29
8.	-1 ▼	Morocco	71.64
9.	0 –	Chile	69.66
10.	0 –	India	69.22
11.	4 ▲	Lithuania	65.06
12.	0 –	Malta	64.39
13.	6 ▲	Germany	63.82
14.	-3 ▼	Finland	62.74
15.	-1 ▼	Switzerland	61.98
16.	1 ▲	Portugal	61.45
17.	6 ▲	France	61.33
18.	3 ▲	Luxembourg	61.03
19.	10 ▲	Netherlands	60.81
20.	0 –	Ukraine	60.52
21.	1 ▲	Egypt	59.83
22.	-6 ▼	European Union (27)	59.53
23.	new	Philippines	58.98
24.	10 ▲	Greece	58.55
25.	new	Colombia	58.11
26.	-13 ▼	Latvia	58.06
27.	-3 ▼	Indonesia	57.39
28.	-10 ▼	Croatia	56.26
29.	3 ▲	Mexico	56.19
30.	-3 ▼	Italy	55.70
31.	-5 ▼	Thailand	55.28
32.	6 ▲	Estonia	55.25
33.	-8 ▼	Brazil	55.17
34.	7 ▲	Spain	54.71
35.	-7 ▼	New Zealand	54.49
36.	-1 ▼	Austria	52.80
37.	-4 ▼	China	52.66
38.	-8 ▼	Romania	52.59
39.	-2 ▼	South Africa	51.56
40.	-9 ▼	Slovak Republic	50.90
41.	8 ▲	Cyprus	50.89
42.	0 –	Turkey	50.75
43.	new	Viet Nam	49.35
44.	0 –	Bulgaria	49.02
45.	0 –	Japan	48.94
46.	-7 ▼	Ireland	48.29
47.	-1 ▼	Argentina	47.50
48.	-12 ▼	Belarus	46.91
49.	-9 ▼	Belgium	46.27
50.	1 ▲	Slovenia	43.73
51.	-4 ▼	Czech Republic	42.53
52.	-4 ▼	Poland	41.01
53.	-3 ▼	Hungary	40.71
54.	-11 ▼	Algeria	40.24
55.	6 ▲	United States	37.90
56.	-4 ▼	Russian Federation	35.00
57.	-1 ▼	Malaysia	34.37
58.	-4 ▼	Australia	30.41
59.	-6 ▼	Korea	27.28
60.	-3 ▼	Chinese Taipei	27.11
61.	-3 ▼	Canada	26.73
62.	-3 ▼	Islamic Republic of Iran	26.35
63.	-3 ▼	Saudi Arabia	24.45
64.	-9 ▼	Kazakhstan	19.81

Figure 5: Climate Change Performance Index 2022 Ranking Table Source: https://ccpi.org/

Summary and Conclusion

Climate change refers to a change in climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time period. Major natural sources of climate change are solar variability, changes in Earth's orbit and tilt, plate tectonics, and biological evolution. Various anthropogenic activities lead to emissions of four principal greenhouse gases: carbon dioxide, methane, nitrous oxide

and the halocarbons. These gases accumulate in the atmosphere and have increased with the passage of time.

The increase in greenhouse gases within a small period of human history is a problem since ithas adverse and differential impacts on different sectors and region. Some of the adverse impacts would be: melting of ice cap, rise in sea level, submergence of many island countries and densely populated coastal areas,increasing frequency of extreme weather events etc.

There are certain global parameters that provide indication of warming of climate. Some of these indicators are increasing temperatures over land and ocean surfaces; increasing sea surface temperature and ocean heat content; melting glacial ice and sea ice; rising sea level; increasing humidity and increase in extreme events.

In India, Ministry of Environment, Forest and Climate Change is the nodal agency which has been sending reports to UNFCC. Till now it has already sent two reports titled as India's First and Second National Communications to the United Nations Framework Convention on Climate Change in 2004 and 2012 respectively.

Climate change mitigation involves efforts to reduce or prevent emission of greenhouse gases such as carbon dioxide. Mitigation activities may include increasing the use of renewable energy technology, making older equipment more energy efficient, or changing management practices or consumer behavior. From implementing management strategies to sequester carbon, avoid deforestation and promote reforestation, to encouraging appropriate renewable energy siting or socially responsible investment and divestment from fossil fuels, there are many ways the conservation community can encourage climate change mitigation among land owners and local communities.

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Unit 10: Depletion of Ozone Layer and Acidic Precipitation

Unit Structure

10.0. Learning objectives

After studying this unit you are able to understand about:

- Describe the distribution of ozone,
- Explain the process of ozone depletion and cycleof ozone formation,
- Identify the ozone depleting substances and their sources,
- Explain the mechanism of ozone hole formationover the Antarctica,
- Highlight the impact of ozone depletion.
- Describe the steps taken as remedial measures toovercome the problem of ozone depletion.

10.1. Introduction

Ozone layer is a vital component of our atmosphere. In stratosphere, it acts as a protective layer as it absorbs the harmful ultraviolet radiation and does not allow it to reach the earth's surface. Therefore, the presence of the ozone layer is essential factor in the life environment. Ozone is a very reactive molecule and with the help of a catalyst it is easily reduced to the more stable oxygen. The ozone destroying catalysts are natural as well as manmade. The primary cause of ozone depletion is the trace gases mainly chlorine and bromine, from anthropogenic sources. The depletion of ozone layer was discovered for the first time by Farman in 1985. It was established that, ozone 'hole' has

occurred in the ozone layer over Antarctica. In 1987, the Montreal protocol set legally binding controls on the production and consumption of gases associated with ozone depletion. The outcome of this response is decline in the total abundance of CFCs in the atmosphere and trend of gradual healing of ozone layer. In this module, discussion and deliberation on the causes and impacts of ozone depletion are aimed at.

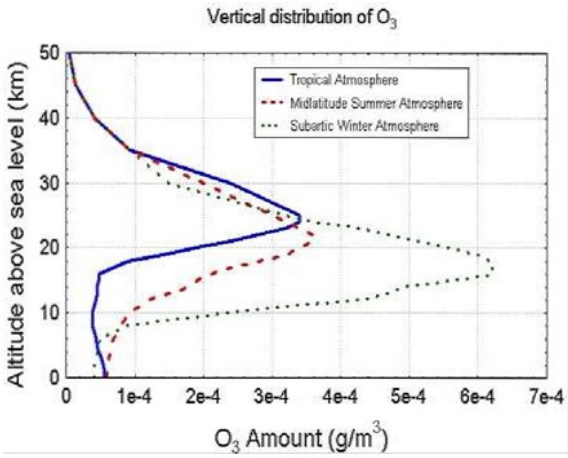
10.2. Ozone

Ozone is a rare gas made up of three atoms of oxygen. You have already studied the composition and structure of earth's atmosphere. You are well aware that the contribution of ozone in the constitution of the atmosphere is very little. Overall its share is just three per every 10 million molecules. Moreover, the distribution of ozone in atmosphere is highly uneven. In troposphere, ozone represents less than one part per 100 million molecules. Still, ozone is a very significant component of atmosphere. It is found concentrated mainly in stratosphere at the height range of 10 to 50 km (Figure 1).Its concentration is much higher in the low latitudes but much lower inthe high latitudes. The maximum is just a few km above the tropopause. Ozone gas is predominantly found in stratosphere and has also a limited presence in the troposphere. Near surface, ozone is undesirable because it is a pollutant. It results into photochemical smog and green house effect resulting into global warming. Here ozone exists as a by-product of photochemical processes between sunlight and pollutants, particularly nitrogen oxides from vehicular exhausts. It is regarded toxic when presence is above sixty parts per billion. It has harmful effects on plant growth as well as causes respiratory problems.

In the stratosphere it is formed through the interaction of the shorter, ultra-violet part of the solar radiation and oxygen molecules, which consist of two atoms of oxygen. Ozone is dominantly concentrated at the height range of 15 and 35 km from surface. The solar ultraviolet radiation breaks-up the oxygen molecules at altitudes above 30 km (i.e. $O_2 \rightarrow O + O$). These separated atoms of oxygen (O + O) when join individually with other oxygen molecules ozone is formedas following:

$O_2 + O + M \rightarrow O_3 + M$

Figure 1. Vertical Distribution of Ozone



Source:http://cimss.ssec.wisc.edu/wxwise/ozone/O3vert.gif

Here, M represents the energy and momentum balance provided by collision with a third atom ormolecule. Ozone is formed due to the collision of a single atom of oxygen (O) and a molecule of oxygen (O_2). This collision requires the presence of a third, neutral molecule to act as a catalyst. The catalyst allows the interactions without being consumed in this process.

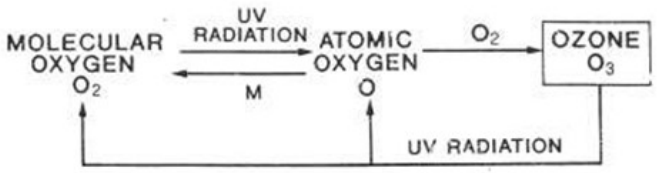
This type of three-body collisions is exceptional at 80 to 100 km above surface, due to very low density of the atmosphere. At height, below 35 km majority incoming ultraviolet radiation gets already absorbed at higher levels. Therefore, ozone is dominantly formed in the height range of 30 to 60 km, where such collisions are more likely. Sydeny Chapman (1930) discovered the basic physical and chemical processes resulting into the formation of ozone in stratosphere. The ultraviolet radiation breaks an oxygen molecule (O_2) intotwo oxygen (O) atoms. These atoms then join with other oxygen molecules to create ozone. Ozone is dissolved when an oxygen atom and an ozone molecule rejoin to give two oxygen molecules i.e.

$O + O_3 \rightarrow 2O_2$

(Figure 2). In the 1950s, David Bates and Marcel Nicolet proved that various free radicals, especially hydroxyl (OH) and nitric oxide (NO), could catalyze this recombination reaction, depleting the overall amount of ozone. These free

radicals are present in the stratosphere. They maintain the natural balance by reducing the overall amount of ozone. It is estimated that in the absence of these free radicals the ozone layer would have thickness twice of the present layer.

Figure 2. Ozone Formation (Chapman Cycle, Oxygen ↔ Ozone)



Source: Barry, R.G. and Chorley, R.J. (1998), P-5.

The Chapman cycle (oxygen ↔ ozone) results into filtering of the harmful ultraviolet solar radiation. Therefore, it works as a protective layer; it absorbs harmful radiation and restricts it to reach the surface. In addition, it helps to trap the weather conditions within the lower atmosphere i.e. troposphere by creating an inversion of temperature in the stratosphere.

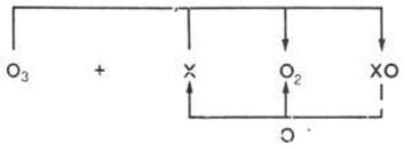
10.3. Ozone Depletion: Process and Causes

Ozone is a very reactive molecule and with the help of a catalyst it is easily reduced to the more stable oxygen. The ozone destroying catalysts are natural as well as manmade. Ozone can be destroyed by a number of free radical catalysts such as (i) OH (hydroxyl) -the odd hydrogen atoms and OH come from the dissociation of water vapour, molecular hydrogen and methane (CH_4); (ii) nitric oxide –ozone is destroyed in stratosphere due to the presence nitrogen oxides (NO_x, i.e. NO_2 and NO). The source gas of theNO_x is nitrous oxide (N_2O) - it is produced by combustion, supersonic jets and fertilizer use; (iii) Chlorine and (iv) Bromine (Figure 3).Anthropogenic activities have sharply increased the levels of chlorine and bromine.

A single chlorine atom has the capability to interact with thousands of ozone molecules in catalytic cycle before it is finally removed. On a per atom basis, the efficiency of bromine is far more than chlorine to destroy ozone, but its abundance is much less in the atmosphere. Therefore, both chlorine and

bromine are the major contributors in overall ozone destruction. The increase in abundance of chlorine and bromine during the decades of 1970-90 is reflected in the observed decrease of stratospheric ozone over the Antarctica and other parts. A simplified illustration is given to show ozone destruction below:

Figure 3: Ozone Destruction Process (where X is any ozone-destroying species, e.g. OH, NO, CR, Br)



Source: Barry, R.G. and Chorley, R.J. (1998), P-5.

The depletion of ozone in the stratosphere due to human activities is a serious global environmental problem. The major offending chemicals are Freons, synthetic compounds containing carbon, fluorine and chlorine atoms. Compounds of this class are also known as *halocarbons*. The popular alternate name for these is*chlorofluorocarbons*, or CFCs. They are versatile compounds that are chemically stable, odorless, nontoxic, noncorrosive, and inexpensive to produce. CFCs, carbon tetrachloride (used in fire extinguishers and solvents), alternates of CFCs - hydrochlorofluorocarbons (HCFCs) and methyl chloroform are the chief chlorine containing gases. These gases are used in many applications such as – refrigeration, air conditioning, foam blowing, aerosol propellants and cleaning of metals and electronic components (Table 1).Methyl chloroform is used in industries for cold cleaning, vapor degreasing, chemical processing, adhesives and aerosols.

The most important source halogen gases for bromine are the halons and methyl bromide. Halons are used to extinguish fires. Methyl bromide, used as an agricultural fumigant, is another significant source of bromine to the atmosphere. Methane and nitrogen oxide, which react in stratosphere to form water vapour and reactive hydrogen and nitrogen oxides, respectively have ozone depletion capabilities. The emission of oxides of nitrogen by supersonic jet planes is also destructive for ozone layer.

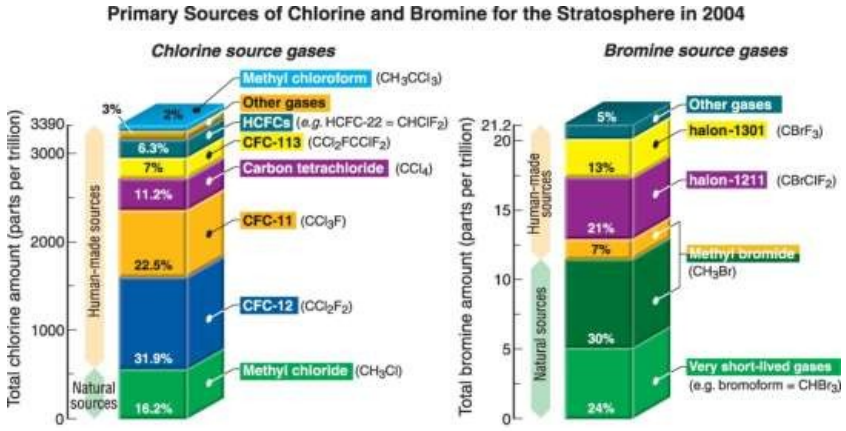
Table 1: Common Chlorofluorocarbons and Halons

Compound (chemical formula)	Ozone Depletion Potential[a]	Atmospheric Lifetime (Years)	Major Uses
CFC-11 ($CFCl_3$)	1.0	64	Rigid and flexible refrigration
CFC-12 (CF_2Cl_3)	1.0	108	Air conditioning, refrigeration,rigid foam
CFC-113 ($C_2F_3Cl_3$)	0.8	88	Solvent
Halon-1211 (CF_3BrCl)	3.0	25	Portable fire extinguishers
Halon-1301 (CF_3Br)	10.0	110	Total flooding fire extinguishersystems
HCFC-22 ($HCCIF_2$)	0.05	22	Air conditioning

Source: Oliver, J.E and Hidore, J. (2003), P-366. ([a]Ozone-depleting potentials represent the destructiveness of each compound in relation to CFC-11, which is given value of 1.0)

There are a few halogen source gases present in the stratosphere that have large natural sources. Methyl chloride contributes about 17 per cent of the chlorine currently into the stratosphere. Likewise, about 30 per cent of the bromine is contributed by natural source methyl bromide (Figure 4). These gases are emitted by oceanic and terrestrial ecosystems. Sunspot cycle shows that global total ozone levels vary by 1 to 2 per cent between the maximum and minimum. Volcanoes can emit some chlorine containing gases. In addition, volcanic sulphur and particulate matter emissions reduce solar transmission and ozone abundance. Sunspots and volcanic eruptions bring only short term changes in ozone abundance. Therefore, the main causes of ozone depletion are anthropogenic.

Figure 4. Natural and Anthropogenic Sources of Chlorine and Bromine in Stratosphere



Source:https://www.esrl.noaa.gov/csd/assessments/ozone/2006/images/Q7-1HighRes.jpg

There was no concern about the negative consequences of nitrous oxide and CFCs until three scientists, Paul Crutzen, F.S. Rowland, and Mario Molina, studied the relationship. In 1970, Crutzen highlighted that emissions of nitrous oxide (N_2O), from increased use of fertilizers and supersonic aircrafts could deplete ozone in the stratosphere, where due to photochemical process it is converted into nitric oxide (NO). In 1974, Rowland and Molina concluded that, like N_2O, the CFCs under ultraviolet radiation in stratosphere would be dissociated and released chlorine atoms will destroy ozone layer. This way they alerted the world through their research work that CFCs were probably reducing the average concentration of ozone in the stratosphere.

Later on, when in 1995 ozone hole formation was reported, Dr Rowland expressed his frustration and stated, "What's the use of having developed a science well enough to make predictions, if in the end all we are willing to do is stand around and wait for them come true. Unfortunately, this means that if a disaster is in the making in the stratosphere we are probably not going to avoid it." In 1995, scholars Crutzen, Rowland and Molina, were awarded the Nobel Prize in chemistry for their pioneering research work on ozone depleting substances.

They discovered that molecules of ozone depleting substances like CFCs drift upward and reach the ozone layer in stratosphere. In stratosphere, CFCs in photochemical process absorb ultraviolet radiation and get decomposed, releasing chlorine. These released chlorine atoms in a complex series of reactions attack molecules of ozone. In a series of chain reactions large numbers of ozone molecules are converted into ordinary oxygen molecules. The chlorine atoms basically interact with ozone molecules by acquiring one oxygen atom to constitute chlorine monoxide (CIO) and leaving behind an oxygen molecule (O_2). As the molecule of chlorine monoxide encounters a single oxygen atom, the oxygen "breaks up" the chlorine monoxide, acquires its oxygen atom and chlorine is released back to indulge in further destruction of ozone in stratosphere. These reactions are chain reactions. In this manner, through chain reactions each chlorine atom that reaches the stratosphere is able to destroy thousands of molecules of ozone resulting into ozone depletion. The simplified reactions are following:

(i) $O3 + Cl \rightarrow ClO + O2$ (chlorine acting as the catalyst)

$O + ClO \rightarrow O2 + Cl$

(ii) $O3 + NO \rightarrow NO2 + O2$ (with nitrous oxide

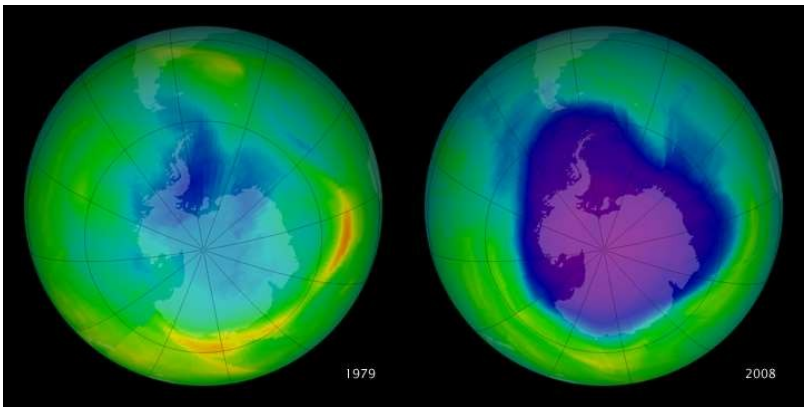
acting as the catalyst)$O + NO2 \rightarrow O2 + NO$

The Antarctica Ozone Hole

The first significant data based on scientific observations about the depletion of ozone layer was presented by Farman and his British Antarctic Survey team in 1985. This team on factual basis established that ozone 'hole' has occurred in the stratospheric ozone layer each spring since 1977 over Antarctica. They observed that for the period 1977-84, the abundance of ozone depleted by 40 per cent during spring season of southern hemisphere. Basically ozone hole is not like a 'hole in the windshield'. The ozone does not disappear in a particular part entirely nor is the depletionin the form of uniform thinning of layer. Therefore, the term holeis representative of more of a depression or decline in quantity. The ozone hole covers about 90 per cent ofAntarctica and

has also expanded over the adjoining oceans. It extends over an area of about 26 million square km. i.e. about the size of North America (Figure 5).

Figure 5: Ozone Holeover Antarctic



Source:http://noair-rors.weebly.com/uploads/5/1/4/5/51453091/288240858.png

The ozone hole develops during the Antarctic spring from September to early December. It is most extensive in October. During this time strong westerly winds start to circulate around the continent and a polar vortex gets established. Due to lack of sunlight temperature decreases and polar vortex traps and chills air to around below -80^0C. These temperatures form polar stratospheric clouds (PSCs). These clouds provide surface for reactive chlorine compounds for chemical reactions leading to ozone depletion.

The role of sun light in ozone depletion is most significant. In winter, PSCs are most abundant but due to absence of sunlight chemical reactions don't take place. During the spring, as the sun comes out, photochemical reactions start along with melting of PSCs. The released CIO drives the ozone hole formation mechanism. At the end of spring season (Mid December) due to warming, polar vortex breaks down, the PSCs are destroyed and air flows from lower latitudes restrict the enhanced ozone depletion and ozone hole closes.The depletion of ozone is measured in terms of reduction in the total column ozone above a point on the earth's surface and it is observed with the help of the

Total Ozone Mapping Spectrometer (TOMS) and measured in Dobson Units (DU).

The Arctic Hole

Kerr (1988) reported that ozone layer depletion is also going on in the Arctic atmosphere. In the Arctic stratosphere, the ozone abundance is more variable than in the Antarctic. The maximum depletion is up to 30 per cent and it is in winter and spring, when the lowest temperatures prevail in stratosphere. Later on it was reported that the background ozone levels have depleted in northern hemisphere to about 15 per cent and the trend was observed over the Mediterranean Sea and the southern United States also. This is of special significance because the northern hemisphere is more densely populated as compared to southern hemisphere and mid-latitude zone is dominated by developed countries. The seriousness and required responses are reflected in the follow up conferences and meetings of the Montreal Protocol.

10.4. Impact of Ozone Depletion

Ozone layer by filtering the harmful ultraviolet radiation functions as a protective shield. In case the ultraviolet radiation reaches the surface with full intensity, it will severely damage the animal tissues and destroy the exposed bacteria. Hence, the presence of the protective ozone layer in stratosphere is essential factor in the life environment. As a consequence of ozone depletion earth surface is exposed to increased ultraviolet radiation. The scholars have estimated that 1 per cent decrease in ozone in stratosphere results into about 2 per cent increase in ultravioletradiation on surface.

Health of Biotic Life: The increased ultra violet radiation due to ozone depletion can cause damage to human health, ecosystems and global climate (Table 2).Ozone depletion intensifies all of the effects of ultraviolet radiation on health of human beings and other organisms. In addition, increase in ultraviolet radiation at surface results into increase in tropospheric ozone. Ozone concentration in lower part of troposphere is a health risk for human

beings and other organisms. Ozone because of its intense oxidant properties, it is toxic in nature. Juvenile and senile age groups and persons with asthmatic and other respiratory difficulties are more vulnerable.

Greenhouse Effect: Near surface, ozone is produced due to photochemical decomposition of NO_2 by ultraviolet radiation into NO and O. Reaction of atomic oxygen with molecular oxygen results into formation of ozone. Ozone formation takes place here, mainly because of interaction of ultraviolet radiation with combustion gases from vehicular exhausts. Ozone in troposphere acts as a greenhouse gas and contributes in global warming. Therefore, ozone depletion on one hand results into global warming and on the other hand in cooling of stratosphere.

Skin Tanning and Cancer

One of the predicted effects of increased ultraviolet radiation is a significant increase in the incidences of skin cancer. The most common skin cancers, basal and squamous cell carcinomas are strongly associated with exposure to ultraviolet radiation. During the decade of the 1990s, scientists in New Zealand discovered that due to depletion of stratospheric ozone concentration, harmful ultraviolet radiation increased substantially. By 2000, peak sunburning ultraviolet levels were nearly 12 per cent more as compared with the levels 10 years earlier in New Zealand. Hence, ozone depletion results into increased incidences of sunburns. The fair-skinned and persons exposed for longer durations have higher vulnerability for sunburn and skin cancer.

Reduction in Human Immune System: The increase in harmful ultraviolet radiation has negative impact of the human immune system. It will be reflected in increased vulnerability to infections and diseases. More exposure to ultraviolet radiation also promotes cataracts. In cataract, the clouding of the eye lens not only reduces vision but may also result into blindness if not treated properly. Epidemiological studies have shown a positive correlation between ocular cortical cataracts and ultraviolet B exposure. To counter the

threat of ultraviolet radiation, schoolchildren in Australia are motivated to use protective hats and sunglasses and also suggested to avoid bright sunlight.

Effect on Crop Yield: The increased ultraviolet radiation has significant effects on plants and animals. One of the major concerns is that the crop yield and quality will be affected negatively. This quantitative and qualitative loss will intensify food insecurity. Exposure of bacteria to additional ultraviolet radiation affects them adversely because of their sensitivity for this type of radiation. Bacteria help in nitrogen fixation and maintenance of soil fertility for economically significant crops. For instance, rice plants for nitrogen depend on cyanobacteria present in their root system. Therefore the production of economically significant crops will decrease.

Effect on Aquatic Life: The additional ultraviolet radiation has potential to eliminate certain forms of aquatic life mainly in the upper layer of water bodies such as oceans, streams and lakes.Some scientists have highlighted the risk of destruction of the microscopic plants, phytoplankton,due to exposure to ultraviolet radiation in waters surrounding the Antarctica. The phytoplankton represents the base of the food chain in marine ecosystems. Therefore, phytoplankton and zooplankton destruction will result into destruction of marine life. On the basis of measurements scholars have concluded that the increase in ultraviolet radiation reduces photosynthesis linearly. The productivity was reported to be declined by a minimum between 6 to 12 per cent.

Table 2: Impact of Ozone Depletion

Human Health	▪ Increase in number and intensity of sunburning cases. ▪ Increase in eye cataracts and blindness ▪ Increased risk for skin cancer (especially basal, squamous cell carcinomas,and malignant melanoma). ▪ Suppression of immune system and increased risk for infections anddiseases. ▪ Positive impact can be reduction in vitamin D deficiency.
Food and Forest	▪ Declined yields and quality of plant products. ▪ Declined seafood supplies due to reduced phytoplankton. ▪ Reduced forest productivity for ultraviolet sensitive tree

	species.
Wildlife	▪ Increased eye cataracts in some species. ▪ Decline in population of ultraviolet radiation sensitive aquatic species. ▪ Reduced phytoplankton and zooplankton. ▪ Increased sunburning of animals. ▪ Ecological imbalances due to decline in primary production.
Air Pollution and Materials	▪ Increased acid deposition. ▪ Increased photochemical smog in lower troposphere. ▪ Degradation of outdoor paints and plastics. ▪ Toxic ozone risk for asthma and respiratory problems.
Global Warming	▪ Increase in tropospheric ozone, CFCs and decreased marine uptake of carbondioxide from atmosphere by phytoplankons. ▪ Stratospheric cooling due to ozone depletion because less ultra violetradiation will get absorbed.

10.5. Measures to Check Ozone Depletion

In 1976, on the basis of scientific evidences a few countries like United States, Canada, Sweden, Denmark, and Norway banned the use of CFCs in aerosol spray cans. The majority of European countries did not ban CFCs in aerosol sprays. After this ban by these few countries, CFCs production initially declined worldwide. But as CFCs continued in use as refrigerants, solvents, propellants and fire extinguishers, there level by 1986 returned back to the its level of 1976.

In 1985, British Antarctic Survey scientists, Farman, Gardiner and Shanklin, on the basis of scientific evidences discovered ozone hole formation over the Antarctica. Taking into consideration the sharp decline in levels of ozone and associated exposure to ultraviolet radiation, scientists and politicians agreed for some positive measures to address the problem. In response to the global threat of ozone depletion and consequent impact on the life environment in 1985 the Vienna Conference was convened by UNEP (United Nation Environment Programme). Members of 43 nations participated in the Vienna

Convention for the Protection of Ozone Layer. The motive of the conference was to promote monitoring, research and sharing of information for the protection of ozone layer to avoid its adverse implications.

In 1987, the Montreal Protocol on substances that deplete ozone layer was signed by the representatives from 43 countries. The participants decided to freeze production of CFCs at 1986 levels by reducing CFCs production by 50 per cent by 1999. In response to ozone depletion trend over the Antarctica and other parts of the world, this protocol was strengthened at a meeting in London (1990). The participants decided to total phase out of CFCs and halon by 2000 by MDCs(More Developed Countries) and by 2010 by LDCs (Less Developed Countries). The phase out date was preponed to 1996 in a meeting at Copenhagen in 1992.

The Montreal Protocol set legally binding limitations on the consumption and production of gases depleting ozone. Over the period of time substitutes were developed and the Montreal Protocol was strengthened and enhanced many times. More than 190 countries have ratified the treaty, including India.

The Montreal Protocol shows a quick and positive international response to a global environmental threat. The outcome of this response is decline in the total abundance of CFCs in the atmosphere. The U.S. Environmental Protection Agency has reported that over most of the world the ozone layer has not depleted thinner since 1998. The scholars have projected that between 2060 and 2075, the level of ozone depleting gases will be at the level that existed before the formation of the Antarctic ozone hole.

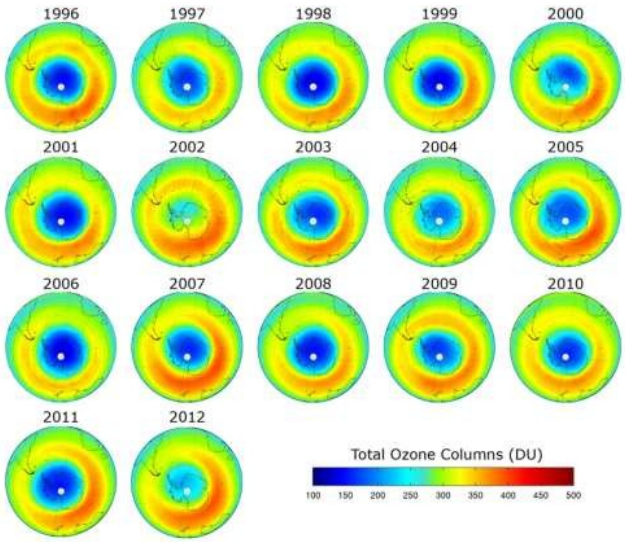
The hydro chlorofluorocarbons (HCFCs) and hydro fluorocarbons (HFCs) have replaced CFCs. The HFCs do not have chlorine or bromine and therefore, do not result into ozone depletion but they are potent greenhouse gases. An ozone-safe refrigerant known as “Greenfreeze” is in use as an alternative to CFCs.

The Montreal Protocol and use of substitutes and alternatives of CFCs reflect positive results. The ozone levels have stabilized and trends of recovery

have been observed (Figure 6). In 2012, UNEP report stated that in the last decade global ozone, including polar areas, showed no depleting trend. The scholars have projected that ozone layer will recover to its pre-1980 levels by some time before the middle of this century and in polar areas by 2060-2075 (Figure 7). Studies have reported a gradual trend towards “healing” of ozone layer in 2016.

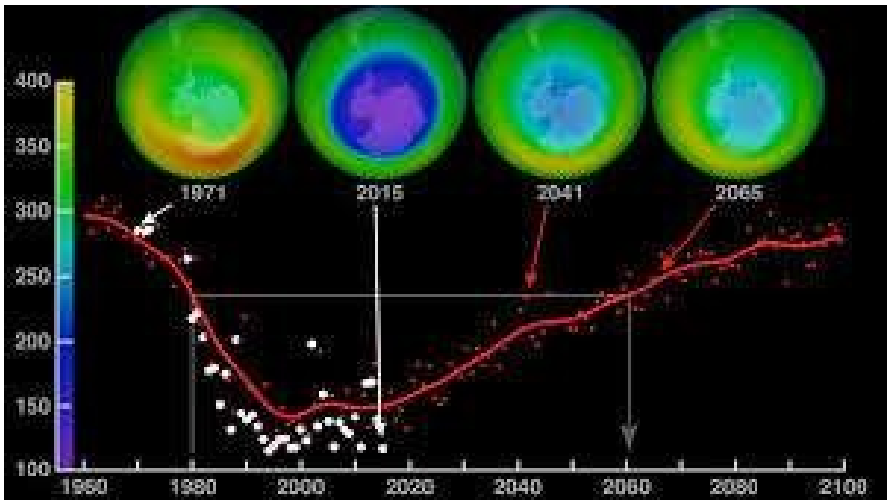
The Montreal Protocol and development of alternatives and substitutes of CFCs has shown positive results.Ozone levels stabilized in the 1990s following the Montreal Protocol, and have started to recover. The UNEP report (2007) showed that the hole in the ozone layer wasrecovering and the smallest it had been for about a decade. The 2010 report found, "Over the past decade, global ozone and ozone in the Arctic and Antarctic regions is no longer decreasing but isnot yet increasing. The ozone layer outside the Polar Regions is projected to recover to its pre- 1980 levels some time before the middle of this century. In contrast, the springtime ozone hole over the Antarctic is expected to recover by 2060 –2075). A gradual trend toward "healing" was reported in 2016.

Figure 6: Ozone Hole Trend, 1996-2012



Source:http://mygoodplanet.com/wp-content/uploads/2016/07/South_Pole_ozone.jpg

Figure 7. Projected Ozone Hole Recovery



https://en.wikipedia.org/wiki/Ozone_depletion#/media/File:Ozone_hole_recovery.jpg

10.6. Summary and conclusions

Ozone layer is a very significant component of our atmosphere. It acts as a protective layer as it absorbs the harmful ultraviolet radiation and does not allow it to reach the earth's surface. Therefore, the presence of the ozone layer is essential factor in the life environment of our planet. In stratosphere, oxygen ↔ ozone cycle operates as Chapman cycle. Ozone is a very reactive molecule. It is easily reduced to more stable oxygen form with the help of catalysts. The ozone destroying catalysts are natural as well as manmade.

Ozone can be destroyed by a number of free radical catalysts such as - OH (hydroxyl), nitrogen oxides (NO_x, i.e. NO_2 and NO), Chlorine and Bromine. Anthropogenic sources have dramatically increased the levels of chlorine and bromine. Over the decades, many uses were developed for Chlorofluorocarbons (CFCs), including as coolants for air conditioning and refrigeration equipment, cleaning solvents for electronic components, propellants for aerosol sprays, and production of certain plastic foams. Halons used as fire retardants result into ozone depletion. The emission of oxides of nitrogen by supersonic jet planes is also destructive for ozone layer.

Crutzen (1970) and Rowland and Molina (1974) pointed out that emissions of nitrous oxide and CFCs have capacities to destroy ozone. The first significant data about the depletion of ozone layer was presented by Farman (1985), the leader of British Antarctic Survey team. He established that, ozone 'hole' has occurred in the stratospheric ozone layer over Antarctica each spring for the period 1977-84. The ozone abundance declined by about 40 per cent during each spring in this period. Later on ozone depletion was also reported over Arctic and northernhemisphere mid-latitudes.

Ozone depletion results into increase in ultraviolet radiation reaching the earth's surface. The increased ultra violet radiation due to ozone depletion can cause damage to human health, ecosystems and to the global climate. Ozone depletion would magnify all of the negative effects of ultraviolet radiation on human health such as sunburns, skin cancers, and cataracts. The effects of additional ultra violet radiation on animal and plant life are also important. There is serious concern that crop yield and quality will be adversely affected.

In 1987, the Montreal Protocol set legally binding controls on the production and consumption ofgases associated with ozone depletion. Montreal Protocol represents a positive international response to a global environment problem. As a result of the action, the total abundance of ozone depleting gases in the atmosphere has started to decrease recently and a healing trend is visible.

Unit 11: Pollution of International Water

Unit Structure

11.0. Learning objectives

The aim of this lesson is to introduce the global concept of water, its importance and distribution. The objectives of learning this module are to highlight the following:

a) Importance and properties of water

b) Presence of water in all spheres of the earth.

c) The cyclic movements of water

d) The nature of water present in various reservoirs

e) The concept of Water Balance Equation

f) The quality aspects of water.

After attending this module, the learner will be able to explain about the distribution of global water masses, inventory of the reservoirs of water and the importance of water balance concepts on the earth.

11.1 Introduction

Water is the most precious gift of Mother Nature. Water is used for drinking, domestic purposes like cooking, washing, gardening and cleaning operations, industrial processes and agricultural activities. Today, water has become a valuable commodity to man-kind. Water has economic value. Without water, there can be no life. It is a basic substance occurring as solid, liquid and gaseous states. Earth is probably the only planet containing plenty of water on its surface. The growing concern of environment demands more insight into the world's water resources. Water is one of the fundamental resources on the earth. Water is essential for all other life. It plays a major role in all aspects of human life.

Hydrology is the scientific study of the origin, occurrence, properties, distribution, and effects of water on the Earth's surface, in the soil and in the underlying rocks, and also in the atmosphere. The subject of hydrology is central to several concepts in physical, chemical and biological sciences and engineering applications. It is founded upon other sciences like meteorology, geology, agricultural physics and chemistry, and botany. Understanding of the world's water masses as a part of the global segments is necessary for managing these resources. The World's water masses are the major reservoirs involved in hundreds of natural processes happening on the earth. These masses are fully under a dynamic condition. What is seen in a day may not be there in the next day in that form or shape or condition. The World's water is an interesting topic to learn.

11.2 Water is available every where

Water is unevenly distributed in almost all parts of the world. Due to its uneven distribution and availability it is to be managed and properly used for a long-term

sustenance of life on earth. The increase in population and human activities, demand for more use of water. Shortage of water is observed in some parts of the world. Water scarcity, water pollution, drought, desertification and famine, all are serious concerns of life on earth. The challenges of managing this resource require proper water education, training and public awareness on water resource management. As a mass, water is not restricted to any one part of the earth.

11.2.1 Water exists in all Segments of the Earth

The origin of water on earth dates back to several million years. In the early history of the Earth's formation, around the time that the Earth's crust began to form, severe volcanic activity released lots of volatile gasses, including water, from the underlying mantle. These volatile gasses made up the early atmosphere and oceans. It is thought that almost all of the water that we find in the oceans, lakes, streams, atmosphere, and the subsurface today was out gassed at this time. This water mass has been cycling and recycling all through these centuries. The connate water (fossil water) occurring in deep sedimentary rocks and the magmatic water emanating from the deep mantle are the major evidences for such origins and evolutions.

Now, water exists in all the environmental segments of the earth. It is available

a) As water vapour in the atmosphere,

a) as ice caps,

b) as soil water and ground water in the lithosphere,

c) as surface water in the hydrosphere and

d) finally, in most of the components of the biosphere.

Water is the most common substance on earth. Every living thing consists of some amount of water. Fruits, vegetables and poultry contain plenty of water in them.

11.3. Water is a unique substance

Water has a large number of interesting properties. These make it an ideal medium to support life. Water is called as the universal solvent due to its extraordinary ability to dissolve a large number of naturally occurring and man-made substances. Water's melting and boiling points make it possible for all three phases to exist on our Planet Earth. Water is also lighter when it freezes, so that it floats. If water sank, then

The bottom of our oceans would be solid. Under such circumstances, we would only have a thin layer on the surface that would be only liquid. There would be far less

global ocean currents, and many of our nutrients would be locked up inside. Survival of global life would be much more difficult, if these properties are not possessed by water. The water molecule is also polar enabling it to dissolve and transport a wide variety of chemicals and mineral substances.

Water has the ability to dissolve many organic and inorganic substances in more quantity than any other liquid on earth. It has the highest heat of evaporation than any other liquid. Huge amounts of heat energy are required to evaporate even small quantities of water. Due to this high heat capacity and the presence of water on all parts of the earth, extreme fluctuations in local temperature, is prevented. Global climate is controlled due to the properties of both water and air.

11.3.1 Inherent properties of water

Water has the following inherent properties:

a) Transformation from liquid to vapour due to evaporation.

b) Transformation from vapour to liquid to solid through freezing.

c) Ability to flow downwards due to the action of gravity.

d) Ability to flow overland on any slope.

e) Ability to move due to the action of wind, when it is in vapour form.

11.3.2 Characteristics of water

Water can be a solid, liquid or a gas. Water has very typical physical and chemical characteristics. Water has the tendency to break down into hydrogen and hydroxyl ions. This process is known as dissociation. The ability of water to conduct electrical changes is yet another property. Similarly water has the ability to conduct heat. Water has a greater heat capacity than other substances, except ammonia. Water's surface tension is also extremely high.

The specific properties of water acting on these circulation are:

1. Specific heat and latent heat
2. Pressure, capillary forces and osmotic forces
3. Density (or) specific gravity
4. Unique melting point and boiling point
5. Compressibility and Viscosity.

Pure water (H_2O) is clear and colorless. It is tasteless. It has no smell. At 1 atmosphere, it has a melting point of 0°C and a boiling point of 100°C. pure water has

a density at 4°C of 1.00 g/cc. Water is a polar molecule and highly cohesive. The polarity of the water molecules results in high surface tension and high solvent ability. It is due to this fact that water is considered to be the 'universal solvent'. One of the most important physical properties of water is its expansion upon freezing. Water increases in density until a temperature of 4° C. is reached, after which it slowly expands until at 0° C upon solidifying, it expands about 10 per cent. After solidification, water again contracts, i.e., increases in density, with decrease in temperature.

11.3.3 Typical properties of water

The capillarity of water rising up through capillary tubes is yet another property of water. This property helps the plants to get water from the soil matrix along with nutrients. The dissolving ability of water is a major factor for several environmental, geological, hydrological and other processes. Water can dissolve many substances.

Water can dissolve mineral species present in hard rocks, soft nutrients, and also the waste food materials that are consumed by people and animals. Water has the ability to flow under the influence of gravity. Water can also exert hydrostatic pressure. The density of water is an important property. Due to the

dissolution of salts and minerals, the density increases. This, in turn, increases the hydrostatic pressure of water.

11.4. The Hydrosphere

The term 'hydrosphere' refers to the sphere of water on earth. It is derived from the Greek word, "hydor" means water and "sphera " means sphere. It refers to the water on or surrounding the surface of the globe. It is the segment that includes all forms of water distributed over atmosphere, lithosphere, and biosphere. When we think of the planet earth, both the land and oceans come to our mind. Land makes only a small part of the world's surface but water makes up to 70% of the earth's surface. Water is not only present is seas and oceans, but also as ice caps glaciers, rivers, lakes, reservoirs, soil water, ground water and atmospheric water vapour.

Similar to the variation of pressure and temperature with reference to altitude in atmosphere, there is a remarkable variation in the physic-chemical properties with reference to the depth of water masses.

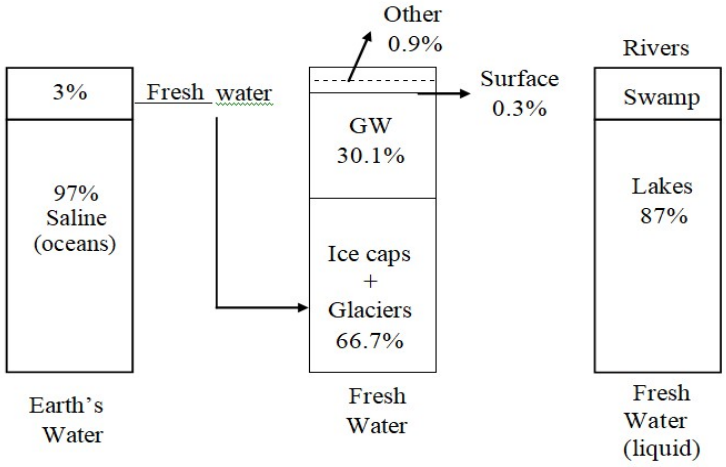
The average annual rainfall over land amounts to 119 000 km3. Out of this, some 74 000 km3 of water gets evaporated back into the atmosphere. The remaining 45 000

km3 of water flows into lakes, reservoirs and streams or infiltrate into the ground to replenish the subsurface formations. This represents what is traditionally known as the "water resources of the world". Not all of these 45 000 km3 are accessible for human use. This is due to the reason that part of the water flows into rivers and during seasonal floods.

An estimated 9 000 - 14 000 km3 of water alone may be economically available for human use and consumption. The actual annual withdrawals of water for human use amounts to about 3 600 km^3.

11.4.1 Distribution of water on Earth

The earth has about 1.386 billion cubic kilometers of water. In this, about 97% lies in the form of seas and oceans, containing salt water. More than 2% exists as ice caps and glaciers, and about 1% is spread in the form of rivers, lakes, ground water and water vapour.



Almost 97% of the water existing in the hydrosphere is distributed as seas and oceans. These are all saline water masses. They are not suitable for direct consumption like drinking, cooking and for industries and irrigational purposes. Only 3% of the water available on earth is fresh water. If we look at the further distribution of freshwater alone, almost 66.7% is locked up in the form of ice caps and glaciers. About 30.1 % is existing below the surface as groundwater. The surface water, which is directly available on the land surface is only 0.3% the rest 0.9% are existing as water vapour

and soil water. The surface water available as 0.3% is shared by lakes, swamps and running water as rivers. In this, a very small proportion exists as biological water.

If all the earth's water are put together, is the form of a sphere, then the diameter of that water ball would be about 1385 km. If we consider the volume, it would be a very small ball in front of the total mass of the earth.

11.4.2. Inventory of World's Water

Reservior	Volume (million Km^3)	Percent of Total	Reproduction Rate Cu.Km/ year
Oceans & Seas	1370	96.5	452
Ice caps & Glaciers	24	1.74	3
Ground water	60	1.74	12
Rivers, Lakes & Swamp	0.2812	0.0132	39
Soil moisture	0.083	0.001	83
Water vapour	0.014	0.001	525
Biosphere	0.0011	0.0001	39
Total	1454.3793	99.9953	1153

All of these water masses are called as water reservoirs of the earth. On an average water is renewed in rivers every 16 days. Water in the atmosphere is completely replaced once in every 8 days. The replacement is show in lake lakes, glaciers and in groundwater systems. The reproduction rate also varies from one reservoir to the other. It is highest for the water present in the atmosphere and lowest in the ice caps and glaciers.

11.4.3. Residence time of water in major reservoirs

The residence time of a water reservoir within the hydrologic cycle is the average time a water molecule will spend within that reservoir. It is a measure of the average age of the water in that reservoir. Residence time can be estimated in two ways. The more common method relies on the principle of conservation of mass and assumes that the amount of water in a given reservoir is roughly constant. In this method, the residence times are estimated by dividing the volume of the reservoir by the rate by which water either enters or exits the reservoir. Dating the age of water using isotopic techniques is the second popular method. The following table shows the approximate residence time of water in major reservoirs.

Major Reservoirs	Approximate Residence Time
Oceans and seas	>100000 years
Glaciers	40 years
Seasonal Snow Cover	0.4
Soil moisture	0.2
Shallow Groundwater	200
Deep Groundwater	10000
Lakes	100 years
Rivers	0.4 years

The residence time of water in the atmosphere is about 9 days before condensing and falling to the Earth as precipitation. Deep groundwater may stay over 10,000 years beneath Earth's surface. The Ice from the Antarctica has been estimated to the age of 800,000 years before present.

11.4.4. Country-wise water resources

According to the Food and Agriculture Organization (FAO), the total water resources in the world are estimated in the order of 43 750 km3/year. This is distributed throughout the world according to the patchwork of climates and physiographic structures. At the continental level, America has the largest share of the world's total freshwater resources with 45 percent, followed by Asia with 28 percent, Europe with 15.5 percent and Africa with 9 percent. In terms of resources per inhabitant in each continent, America has 24 000 m3/year, Europe 9 300 m3/year, Africa 5 000 m3/year and Asia 3 400.1 m3/year.

At a country level, there is an extreme variability in these resources. The ten poorest countries in terms of water resources per inhabitant are Bahrain, Jordan, Kuwait, Libyan Arab Jamahirya, Maldives, Malta, Qatar, Saudi Arabia, United Arab Emirates and Yemen. In the large countries, water resources are also distributed unevenly in relation to the population. In addition to spatial variability, there is a high variability in time within the year or among different years.

Thirty-three countries depend on other countries for over 50 percent of their renewable water resources requirement. They are Argentina, Azerbaijan, Bahrain, Bangladesh, Benin, Bolivia, Botswana, Cambodia, Chad, Congo, Djibouti, Egypt, Eritrea, Gambia, Iraq, Israel, Kuwait, Latvia, Mauritania, Mozambique, Namibia, Netherlands, Niger, Pakistan, Paraguay, Portugal, Republic of Moldova, Romania, Senegal, Somalia, Sudan, Syrian Arab Republic, Turkmenistan, Ukraine, Uruguay, Uzbekistan, Viet Nam

and Yugoslavia.

11.5. Cyclic movement of water

The world's water is not in static condition. It moves from one reservoir to another reservoir and also from one state to that of the other. Water is in constant motion and circulated between all these reservoirs. The earth's water moves from the oceans to the air, air to the land and land to the oceans, again and again.

The sun's radiant energy evaporates oceanic waters into the atmosphere, as water vapour. This moves towards the land and falls back as rain, snow and sleet. These slowly flow overland, fill up the lakes, swamps and streams. A part of these water masses percolate inside the ground and join the groundwater. The other surface water masses may flow towards the sea and are subjected to evaporation and transpiration processes. This endless circulation of water masses among these reservoirs is known as the hydrologic cycle. The hydrosphere interacts with the atmosphere and lithosphere mainly through the water cycle

11.5.1. Natural reservoirs and conduits

Much amount of water on earth, gets circulated within the lower part of the earth's atmosphere. In this region, water vapour is transported is all directions. The net effect is the movement from sea to air and from air to land. The wind and pressure belts play a significant role in this movement. The shape, type, size and location of the reservoir play a dominant role. This also varies above the surface and below the surface. Water flowing in streams ultimately reach the lakes or seas faster than the water which is flowing below the surface.

The water entering into a lake after a rainfall may be locked up from the movement, for several days and months. Similarly, the water percolating below the rocks through deep fractures in the earth's crust may also get locked up for many years. Some fossil waters entrapped under geological beds of rocks may be of several thousand years in age. It is also an important fact that the age of the water residing in the oceans may be of several million years.

11.6. The Hydrologic Cycle

The hydrologic cycle involves a set of processes that are everlasting processes. The components of the hydrologic cycle, are:

1. Precipitation
2. Infiltration
3. Surface runoff
4. Transpiration
5. Groundwater base flow
6. Interception
7. Evaporation from free water surfaces
8. Condensation
9. Evopotraspiration

The hydrologic cycle forms the central concept in all the scientific studies of water. Human pressures at global to basin scales are substantially modifying the global hydrologic cycle. It has severe adverse impacts on its interconnected aquatic ecosystems – both freshwater and marine – and therefore on the well-being of people who depend on the services that they provide.

11.6.1. Components of the Hydrologic Cycle

The dynamic movements are coupled with changes in the states of matter from liquid to vapour, vaopur to solid and liquid sequences. The movements are also not uniform. There are varying rates and there are many short circuits in the cycle also. Sometimes, the residence time of water in a reservoir gets increased due to stagnation of water in that reservoir. The routes of movement also varies. Some masses follow the aerial routes, and some of them follow the subterranean (subsurface) routes. Much amount of water that are flowing over the land, reach the seas and oceans, above the surface. Groundwater also moves under the ground and follows the subsurface path.

Some amount of surface water may leave directly in to the atmosphere through direct evaporation from surface water bodies and also through transpiration by vegetation. The rainwater falling on the leaves of vegetation also may get evaporated back in to the atmosphere within a short span of time. This is called as interception. The water of the snow fields may get evaporated directly into the atmosphere. It is called as

sublimation. The rates of movement of water and the quantities of water involved in the cyclic process are the major aspects involved in the hydrological sciences.

The water vapour that are accumulated as condensed clouds of the atmosphere, get precipitated in the form of rain and snow and fall on the earth's surface, in liquid or solid forms. The rainwater flows as surface water over the land or infiltrates into the ground.

11.6.2. No beginning and No end

Since the world's major amount of water gets stored in the seas and oceans, it is quite natural to assume that the hydrologic cycle starts from oceans and from evaporation. Similarly, the precipitated rainwater may also be presumed to be the starting point of hydrologic cycle, as it comes from the atmosphere directly as the primary source. Though we feel that the hydrologic the cycle begins from evaporation (or) precipitation, it has no beginning and no end. It is a never ending cycle. It has endless circulation.

11.6.3. Factors controlling Hydrologic Cycle

Several factors control the circulation of water on the earth. The following are the major factors, controlling the hydrologic cycle:

1. Nature and application of energy that promotes circulation.
2. Inherent properties of the water, air and other masses
3. Structure of the natural reservoirs and their conduits (channels) promoting movement
4. The earth's gravitational attraction, which is responsible to activate the flow.

The hydrologic cycle has a direct link with the monsoon cycle of a region. Any drastic climatic variation or climatic change that are occurring on the globe will have a direct consequence on the circulation pattern of water on the earth.

11.6.4. Source of Energy

The principal source of energy which mainly drives the circulation process in the hydrologic cycle is the sun's radiant energy. It has the ability to transform water from one state to the other. All the mechanical and chemical works are also controlled by the radiation. Solar energy can raise the temperature of water, air, soil and promote various processes at different altitudes and latitudes.

Adolph. F. Meyer, in the Elements of hydrology, explains the role solar energy for water circulation. The sun's energy vaporizes the water from the surface of the earth. The vapour thus formed is lighter than the dry gases of the atmosphere, and hence it tends to rise. Aided by the convection currents, the water vapour moves from place to place and upward through the air. On rising, it encounters a rarified atmosphere and expands.

The energy required for the work of expansion is drawn from the air itself, resulting in a cooling and ultimate condensation of some of the vapour which falls to the earth again as rain. The precipitated water then starts on its way back to the ocean. Some of it is lost through evaporation and some is used by growing plants. The most complete conservation of water can be secured only by its fullest utilization, for so long as the sun shines.

11.7. Distribution of Water in various reservoirs

11.7.1. Water in the World's Oceans

As seen already, 97% of the world's water lies in oceans. Oceans have two inputs. One is the direct precipated rainfall, which accounts for about 90% and the other one is the runoff from the lands, which accounts for about 10%. Oceans have only one output as direct evaporation. The residence time of water in the oceans is about 3000 years. The water which reside near the surface of the ocean have shorter residence time than the water of the deep ocean.

The deep water of oceans may have the residence time of hundreds of thousands of years.

- Only the water available at the surface of the ocean is involved in evaporation.
- Ocean water contains about 35gm/L of dissolved salts, making it unfit for drinking and other purposes.
- Distillation is the only way of making freshwater from sea water.
- Every day the sun evaporates millions of metric tons of water from the oceans.

The distribution of water in the world's oceans are as follows:

Ocean	Area in M.Sq.Km	Volume M.C.Km
The Pacific	181.3	714.4
The Atlantic	94.3	337.2
The Indian	74.1	284.6
The Antarctic	20.3	--
The Arctic	12.25	13.7
Total	382.25	1349.9

Oceanography is the branch of science that is dealing with the physical, chemical, geological, and biological features of the seas and oceans. Oceanography deals with salt waters, whereas limnology (Gr. limn, lake) usually deals with fresh waters.

11.7.2. Water vapour in the Atmosphere

Moisture exists, in the atmosphere

1) As an invisible form called as water vapour
2) As liquid in the form of water molecules
3) As solid in the form of snow or ice.

The amount of water vapour present in the atmospheric air is called as humanity. The amount of water present in the atmosphere is volume-wise is equivalent to the volume of water flowing through the rivers all over the world.

If we look at the rate of exchange between the water in the atmosphere and on the earth, everyday, it shows that approximately 2.5mm falls as rain and about 2.5mm of water gets evaporated from the surface. The average residence time of water in the atmosphere is about 10 days. It is also found that there is a complete exchange of atmospheric moisture 40 times a year.

11.7.3. Water in Rivers and Streams

The rivers all over the globe seem to be primary reservoirs of water. The volume of water in the earth's streams is very small, accounting to only 0.001% of the total world's water. The flowing water along the streams at an average rate is found to be of 3m3/second. (3 Cu. M per second). Although, the volume of water in rivers at a given time is small, the total volume flowing through them over a period of time is enormous. The input mainly comes from precipitation and groundwater base flow. Approximately half of the total river water inflow to the world ocean falls into the Atlantic ocean, from the Amazon, the Congo, the Orinoko and the Parana Rivers. Least amount of rainwater flows into the Arctic Ocean.

11.7.4 Water as Ice and Snow

The fresh water available on the earth in the form of ice constitutes about 80% and is 2% from the world's total water resource. Most of these are located in the great

glaciers that cover the North America and the Greenland, the Antarctica, Asia and Europe. Ice within glaciers moves slowly towards the margins and its gets melted.

Snowfall over an area is more uniform than rainfall. Snow accumulation is largely a function of elevation, slope, exposure, and vegetative cover. The total snow cover of the earth is 72 million sq.km, sea ice is 26 million sq.km., ground ice is 32 million sq.km., glaciers and ice-sheets cover about 16 million sq.km., and icebergs is about 63 million sq.km. The atmospheric ice alone covers an area of 510 million sq.km.

The residence time glaciers may be for 1000's of (or) even millions of years. The melting of ice from glaciers will have a major role to play in rising the water level of oceans. If the existing glaciers melt completely, the oceans would increase to about 2% and the sea level would rise about 100m.

The following table shows the distribution of water as glaciers and ice across the globe.

Location	Volume (103 km^3	% of total volume in hydrosphere	% of freshwater
Glaciers and permanent snow cover	24,064	1.74	68.7
Antarctica	21,600	1.56	61.7
Greenland	2,340	0.17	6.68
Arctic Islands	83.5	0.006	0.24
Mountainous regions	40.6	0.003	0.12
Ground ice(permafrost)	300	0.022	0.86

11.7.5 Water in Lakes

Lakes constitute about 0.017% of the world's water resources. More than half of this is held in fresh water lakes, and the rest is in saline lakes. Almost 75% of the total volume of freshwater lakes are found in North America, USSR and East Africa.

Lakes occupy about 1.8 % of the earth's surface. Almost 304 million standing water bodies are existing in the world. Small lakes are more in number. About 60% of the world's lakes are in Canada. Finland is known as the land of 100 thousand lakes.

The Caspian Sea is one of the largest saline lakes in the world. It has a water residence time of 200 years. For freshwater lakes, the residence time is as low as 90 years. Lakes provide an important source of water for irrigation and domestic water supply. Local climate is also controlled by lakes.

11.7.6 Water as Soil Moisture

The soil matrix and the geologic materials (i.e., rock, and sediments) have some amount of empty space in them. This empty space is called as the pore space. The percentage of pore space by volume in a rock or sediment is called as the porosity. Within all naturally-occurring geologic units, the pore space always contains some amount of moisture. If it is seen in soils, it is called as soil moisture.

The soil moisture is the term applied to the water held in the soil by means of molecular attraction. Water forms a thin film around the soil particles and fill up the small pore spaces of the soil particles. Soil moisture accounts for about 0.005% of the world's water masses. This is the major source for all vegetation to survive. The average residence time of water in the soils is about 1 month. The amount of moisture present in soils differ with reference to the physic-chemical properties of soils, the climatological factors of the area and geomorphic conditions. It is also varying over crop lands and agricultural regions.

11.7.7. Groundwater as a Source

Groundwater is one of the important reservoirs of water on earth. It is the water stored in the pore spaces of subsurface geological formations. The subsurface/vertical distribution of groundwater is divided into two zones as, zones of aeration and saturation. The zone of aeration consists of interstitial openings that are occupied partially by water and partially by air. In the zone of saturation, all the interstitial spaces are filled with water, under hydrostatic pressure. It is also a fact that on most parts of the land masses of the earth, a single zone of aeration overlies a single zone of saturation and extends upward to the ground surface. The depth of the aquifer also goes into several hundred meters below the surface.

The occurrence, distribution and movement of groundwater depends on the hydrological properties of the geological formations. The hydraulic properties of soils and rocks depend on the sizes and shapes of the void spaces. These may vary over very short distances. The water bearing geological formations are called as aquifers. Groundwater gets replenished through natural recharge from rainfall. This system supplies water for a major portion of population all over the world. This resource gets depleted due to over exploitation. Springs are seepages coming out of the where groundwater touches the surface.

Groundwater has its own residence time. The residence time of groundwater depends on several factors including seasonal inputs from rainfall and output as base flow. The base flow consists of water that infiltrates into the ground during and after a rain storm. It also relates to the sustaining stream flow during dry periods and between storm flows. The source of base flow is the groundwater that flows through unsaturated and saturated soils and cracks or layers in bedrock or other impermeable layers adjacent to the stream.

11.7.8 Water in Living Organisms

Water and life go hand-in-hand. The total amount of water stored in the living organisms is extremely small, when compared with the other reservoirs. Plants play a dominant role in utilizing the water and release it back to the atmosphere. Life is tied up with water, air and food, while food is tied to water. Though water is a regional resource, its shortage is becoming a global issue due to increasing population, economic growth and climate change.

The residence time of water is also very short. It ranges from a few hours in warm blooded animals to a season for most plants. Development of new sources of water, besides its efficient use, together with conservation measures, should be an important component of any country's national water resources development plan.

11.8 Water Balance Equation

The water balance equation provides a quantitative means of evaluating the hydrologic cycle and the world's water masses. The equation considers the inflow, outflow and changes in storage as

Inflow = Outflow ± changes in storage.

This equation can be expanded as $P - E - T - Ro = \Delta S$.

Where,

P = Precipitation E = Evaporation T = Transpiration Ro = Runoff

ΔS – Changes in Storage

This equation balances the water availability for a specific time period.

11.9. Human pressure on water resources

According to the assessment made by the United Nations on world's water resources, the available water resources, globally, are found to be continuously declining as a result of excessive withdrawal of both surface- and groundwater. It has also contributed for the decreased water run-off due to reduced precipitation and increased evaporation. This comes due to global warming.

Already, in many parts of the world, such as West Asia, the Indo-Gangetic Plain in India, the North China Plain and the High Plains in North America, human water use exceeds the annual average water replenishment. Use of freshwater for agriculture, industry and energy has increased markedly over the last 50 years. More seriously over 2.8 billion people in 48 countries will face water stress by 2025, based on United Nations medium population projections

There are more than 45 000 large dams in 140 countries. About two-thirds of these dams are in the developing world, with half present in China. These dams, with an estimated potential storage volume of 8 400 km3, impound about 14 per cent of global run-off as estimated by Vörösmarty and others in 1997. The new dam construction is limited largely to the developing regions, particularly Asia. To enhance international cooperation in addressing the exploitation and degradation of water resources, the United Nations proclaimed 2005–2015 as the International Decade for Action, "Water for Life."

A major challenge is focusing attention on action oriented activities and policies directed to sustainable management of the quantity and quality of water resources, in the world.

11.10. Shortage of water

It has been found that there are five major drivers demanding a huge expansion of water resources in the 20th century. They are population growth, industrial development, and expansion of irrigated agriculture, massive urbanization and rising standards of living. Almost 20% of the world's population or more than 1 billion people lack access to safe drinking water.

Water is a carrier of disease vectors contaminated water can cause a host of water-borne diseases. About 80% of all illnesses and more than one third of all deaths in developing countries are related to water.

Almost 1.1 billion people have no clean water. Their distribution is as follows:

1) 406 million people in East Asia and the Pacific
2) 229 million people in South Asia
3) 314 million people in sub-Saharan Africa
4) 38 million people in the Middle East
5) 49 million people in Latin America and the Caribbean

Today, some of the world's biggest cities, including Beijing, Buenos Aires, Dhaka, Lima and Mexico City, depend heavily on groundwater for their water supply. The current overuse is not sustainable, because it takes many years to fill aquifers. It is also a fact that most of the world's megacities are located along the coastlines. In these regions, the aquifer depletion leads to saltwater intrusion and the contamination of freshwater resources.

11.11. Quality of water

In addition to quantity of water, the quality of water available on the earth is also a very significant aspect to be understood. The physic-chemical and biological properties of water determines the quality of water for its suitability for drinking, domestic, industrial and irrigational purposes. The quality of water deteriorates due to contamination (or) pollution and due to various mixing process.

Water quality is affected by chemical, microbiological and thermal pollution. The chemical contamination comes due to excess nutrients, acidification, salinity, heavy metals and other trace elements, persistent organic pollutants and changes in sediment loads.

The microbiological contaminants, bacteria, viruses and protozoa in water pose one of the leading global human health hazards. The altering natural water temperature cycles can also impair the biological functions that can affect the metabolic rates in aquatic organisms, leading to long-term population declines.

Water pollution is a new problem approaching crisis levels in many parts of the world. Polluted water is a major cause of death and disease in the developing world. A water becomes unsuitable, if contaminated with toxic substances. It is a fact that half of the world's rivers and lakes are seriously polluted.

11.12 Importance of World's Water

If the water from land frontiers did not return back to the seas and oceans from precipitation and runoff, then the sea level world drop to about 1m per year. The salinity would also raise and rate of evaporation gets reduced. In such cases all the oceans would be completely dry within 4000 years. It will take 30000 years to till these oceans again through runoff. Water is the Earth's primary integrating medium.

It has a wide potential to reduce poverty, increase food security, improve human health, contribute to sustainable energy sources, and strengthen the ecosystems' integrity and sustainability. These water-related goods and- services represent a very significant and amount of opportunities for sustainable development. This has also been recognized in the Millennium Declaration and at the recent World Summit on Sustainable Development.

Water use is uneven across countries. The 10 largest water users, in the world (in volume), are India, China, the United States, Pakistan, Japan, Thailand, Indonesia, Bangladesh, Mexico and the Russian Federation. Agriculture is by far the main user of water. Irrigated agriculture accounts for 70% of water withdrawals, which can rise to more than 90% in some regions.

11.13. Global Water Management Concepts

The report on the findings of Phase One of the UNESCO-WWAP Water Scenarios Project to 2050, shows the importance of global water management options. It has been concluded that global water management has to address two fundamental categories of uncertainty.

The first one is related to water supply, which is dependent on the geophysical parameters that dictate water availability (precipitation, runoff, infiltration, etc.) as well as on the impacts of human activities that affect the natural flow of water (e.g. how land use affects storm water runoff) and water quality.

Conventional analysis of historical data coupled with stochastic analysis until now has provided a fairly good basis for examining extremes and sensitivities, robustness, resilience and reliability under past climate variability. For water managers, this is the starting point for any realistic analysis, and these kinds of analyses are being done routinely in most managed systems.

The second category of uncertainties relates to variability and the rate of growth in water demands. The number and intricacy of choices seem to be growing beyond leaders' abilities to analyse and make decisions. For example, unforeseeable trends in the rising demand for all goods and services, including energy, affect water in some way through production, transport or disposal. This creates new uncertainties and associated risks for water managers.

Developing countries like India are actively being encouraged to move from the traditional supply- side orientation towards proactive demand management under the broad framework of Integrated Water Resources Management (IWRM). Integrated Water Resources Management (IWRM) is a sound philosophy which is hard to disagree with.

11.14. Conclusion

Water is the source of life and development on our planet. Reliable assessment of the earth's water is very difficult due to the dynamic nature and hydrologic variability of water in time and space. Allied problems exist in estimating global population and total annual renewable freshwater availability internationally. Water problem assessment is a major subject of study. It comprises reliable assessment of water availability, water quality, water needs and water shortage.

A thorough knowledge of the physical distribution of water is needed to solve many problems of the world in relation of water resource management. Water conservation technologies, for example, are slowly becoming more prevalent and can help reduce water use.

The world is not "running out of water," but it is not always available when and where people need it. Climate, normal seasonal variations, droughts and floods can all contribute to local extreme conditions. Water is not in short supply over the earth. It is a duty to conserve the available water resources of the world. The hydrosphere is an important environmental segment of the Earth. It is an essential segment for all life to survive.

11.15. Summary

Water is the most precious gift of mother nature. Hydrology is the scientific study of the origin, occurrence, properties, distribution, and effects of water on the Earth's surface,

in the soil and in the underlying rocks, and also in the atmosphere. Earth is probably the only planet containing plenty of water on its surface.

Water is unevenly distributed in almost all parts of the world. The origin of water on earth dates back to several million years. The term 'hydrosphere' refers to the sphere of water on earth. The earth has about 1.386 billion cubic kilometers of water. In this, about 97% lies in the form of seas and oceans, containing salt water.

More than 2% exists as ice caps and glaciers, and about 1% is spread in the form of rivers, lakes, ground water and water vapour. Only 3% of the water available on earth is fresh water. Studying the world's water is an essential part in dealing with the issues of water resources management. In this module, the importance and properties of water, the presence of water in all spheres of the earth, the cyclic movements of water, the nature of water present in various reservoirs, the concept of Water Balance Equation and the quality aspects of water have been explained. The pressure of humans on world's water masses is also pointed out.

Unit 12: Solid Waste: Types; Sources of solid wastes; The hazardous wastes; The solid waste problem; Management of solid wastes

Unit Structure

12.0 Learning objectives

After reading this unit we probably become able to:

- Define solid waste
- Know about source of solid waste
- Identify and enlist major types of agents (solid waste) deteriorating our environment

- Distinguish between among various types of solid wastes and their respective problems
- Identify various disposal techniques of solid waste
- Know about hazardous waste
- Know that the solid waste as resources

12.1. Introduction

Increasing population, rapid urbanization, booming economy is raising the standard of living in throughout the world. These development activities accelerate the rate of waste generation in rural and urban areas. Solid waste management issue is the major challenge in big and small cities in the India/world. It is because of rapid waste production and low budget for waste management. High cost of waste management practices are burden on developing countries in Asia and Africa.

12.2. Solid waste

Definition, Classification of solid wastes

The "**solid waste**" can be defined as any waste mostly in solid form such as refuse, trash or garbage, discarded material, etc. generated from any household, agricultural, mining, industrial or commercial activities. It also includes wastes as sludge created at waste water treatment plant, water supply treatment plants. Almost each and every activity produces some sort of wastes. However, it is essential to consider that in addition to solid form of waste, other liquid, semi-solid or contained gaseous forms of waste are considered as solid waste.

Solid waste can be classified in various ways. Depending upon the degradability, it can be biodegradable and non-biodegradable solid waste. It can also be classified as hazardous and non-hazardous waste.

12.2.1. Biodegradable solid waste and Non-biodegradable solid waste

a) Biodegradable solid waste

This type of waste is commonly decomposes by microorganism in their constitutional elements. Organic materials based waste is count in this category such as food waste, manure, agriculture waste, dairy waste etc. Organic material based solid waste decomposes by two types; in the presence of oxygen and absence of oxygen. Aerobic

(in presence of oxygen) breakdown of waste under controlled conditions form 'compost' that could be utilize in agriculture applications as a fertilizer. Anaerobic (in absence of air) decomposition of waste produces methane (CH_4) gas. Methane gas serves as a major constituent of biogas that used in various applications of cooking, lighting and heating. The problem with anaerobic decomposition of waste is offensive and irritating smells.

b) Non-biodegradable solid waste

This type of solid waste contains mainly inorganic materials that do not decomposed by microorganism. Metal scrap, plastic containers, plastic bags, glass bottles are some examples of non-biodegradable solid waste.

There is another way to categorize solid waste on the basis of combustibility. These are combustible and non-combustible based on burning and non-burning nature. Some waste materials are classified on the basis of physical and chemical properties whether they are hazardous or non hazardous.

12.2.2 Hazardous waste and Non-hazardous waste

a) Hazardous waste

This type of waste has potential threats to public health or environment. Infectious and corrosive chemical such as acids or alkaline, toxic elements are count in this group of waste materials.

b) Non-hazardous waste

This type of waste material does not possess hazardous natures, but they are still in harmful for human and environment.

12.3. Chemical composition of solid wastes

Chemical formulation is an important feature that helps to plan the waste management options. There are various significant characteristics of chemical composition as follow:

Moisture content: It represents the proportion of water present in the solid waste.

Ash content: After waste material burning, some residues are left that is ash.

Heat content: It is defined as the quantity of heat liberated by burning of waste material also referred as the calorific value.

Complete analysis of solid waste could also identify the various chemical elements. Presently, the waste composition can be known by sorting out the waste components followed by moisture testing, chemical composition testing and ash content testing for each and every waste material in the mixture. Resultant value of these testing on combining determines the overall solid waste composition. Moisture content of municipal solid waste is dynamic property which depends on the season such as in rain, it high and low in dry summer. It is directly depends on the humid conditions and meteorological parameters as well as solid waste composition. The moisture of waste material can calculate by oven dry method. Heat values of waste material analyze by bomb calorie method.

12.4. Sources, composition and characterization of the solid waste

Solid waste that generates in urban area is known as municipal solid waste (MSW) and its management is one among the most challenging environmental issues. The composition of municipal solid waste (MSW) varies from one place to another (municipal corporation to municipal corporation) and such complexity is due certain factors including economic conditions, life style, waste disposal policies and industrialized structures. Appropriate waste management and handling depends upon the nature and amount of solid waste. The quality and quantity of solid wastes are useful and essential aspects to frame energy generation plans from waste and also help to decide the capacity and suitable technology for energy production. Therefore, calorific value, basic composition of MSW can help scientists and engineers to plan the waste to energy production. Such as animal waste is best for generation of biogas via anaerobic digestion and hard wooden ravage is suitable for gasification technology. As per EPA it is found that in 2013 approximately 254 million tons of MSW has been generated in the United States. Such MSW composition and classification is given in Fig. 1.

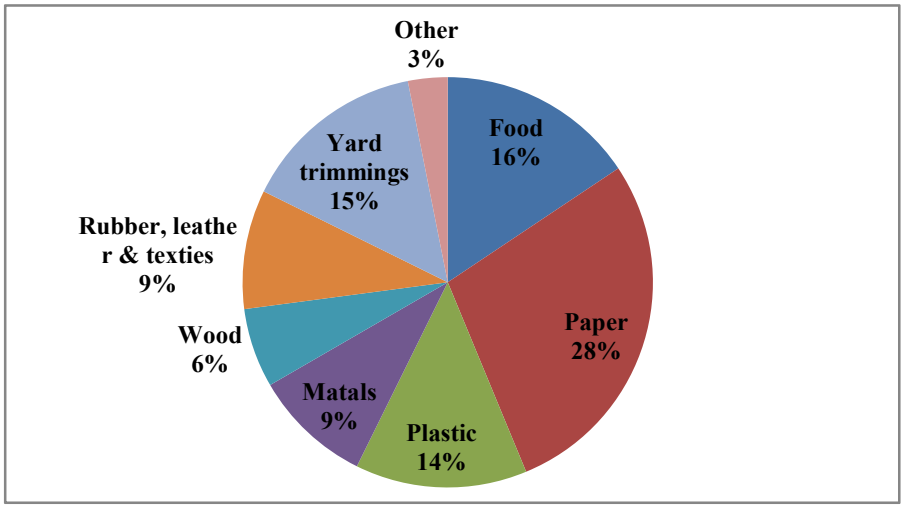


Figure 1. MSW composition in USA

The chief sources of MSW in developing nations include households (55-80%) and marketplaces or commercial areas (10-30%). Industries, streets, institutions are also contributors of MSW. The of nature MSW is heterogeneous means many types of components found such as waste food items, trash, plastic materials, wood chips, waste metal items, papers, yard waste, inert materials, rubbers, textiles, paint containers, batteries, leather, demolishing and building materials and much more that are often not easy to categorize. Thus, the waste generation sources determine its actual chemical composition and characteristics. Segregation of MSW is requirement of current time so that waste can be use for useful applications.

Solid waste materials dispose off at landfill places. The sources of these disposing materials mainly include residential areas, commercial area, industrial units and several farming activities. Foul smell and gases emitted from landfill sites has potential threat to pollute environment. The key sources of solid waste are briefly describes as:

a) Residential

Residences and homes of people where they used to live are the source for generation of various types of waste such as waste food, crockery items, plastics, wood, paper, glass, leather, cardboard, metals, yard wastes, ashes and special wastes like bulky household items like electronics, old mattresses, batteries, tires, and used oil.

b) Industrial

Industrial setups contribute a huge proportion to solid waste generation. Industrial waste includes metals scraps, chemicals, packaging waste, ash etc. Most of the

industrial areas have light and heavy manufacturing industries which generate waste materials.

c) Institutional and commercial

Schools, colleges and government institutions also generate a good amount of solid waste. Commercial facilities such as hotels, markets, restaurants, go downs, stores, office areas are main places includes. Paper, rubber, glass, plastics food materials, electronics are main waste materials groups in the institutional waste. Among these waste materials electronic items are most unsafe waste materials.

d) Construction Sites

Construction sites are most important factor for waste generation in urban areas. Construction requires many types of materials such as stone, plastics, steels, wood, rubber, wires, glass, etc. and these materials share most part of construction waste materials. Construction of building roads, buildings, and reconstruction as well as demolition sites are few major examples related to waste generation sites.

e) Municipal services

These services create many types of waste in urban areas such as street cleaning, landscaping waste, water purification units and waste generated through recreational activities etc.

f) Treatment plants and sites

Large and small manufacturing plants such as power plants, refineries, minerals extraction plants chemicals plants and processing plants generate solid waste. It is a composite type of waste which has unwanted specification products, plastics, metals parts, etc.

g) Agriculture

Leaves, orchards, dairies, vineyard, crops and feedlots are source of solid wastes. It includes spoiled food, containers, and many hazardous chemical which use for pest control and preservation of food.

h) Community waste

These include sweeping, garbage, kitchen waste, night soil, liquid waste, metals, plastics, packaging materials, etc. Community waste may also include toxic materials such as paint, batteries, motor oils, old pesticides and cleaning products.

i) Animals

This includes slaughter house waste, fishery wastes, leather and wool etc. Villages, towns and cities have many animal shelter houses, and dairies that produce huge amount of organic waste. It is commonly considered the excreted materials from live animals and straw, hay, wood shavings, etc

j) Biomedical

These constitute hospital waste, waste biomedical equipments and trash generated from medicine manufacturing units. Hospitals refer to themain source of biomedical waste generator. Used syringes, gloves, drugs, papers, plastics and glass bottles, chemicals, tissues, body parts are major substances of biomedical waste.

12.5. Municipal Solid Waste (MSW) generation in India

MSW generation is variable for one place to another in India and is directly relative to socio-economic status of urban population. About 48 million tones of MSW have been generated in urban India per year with 200 to 600 grams per capita national MSW generation. During 2005-2005 a survey has been conducted in India in about 59 cities by CSIR- National Environmental Engineering Research Institute (NEERI) in association with Central Pollution Control Board (CPCB) with the aim of generated MSW characterization and to delineate or develop a sustainable strategy for MSW management. From the results, it was found that approximately 90% MSW produced in metro cities and Class I cities. In cities, door-to-door MSW collection efficiency was found to be between 74.57% and 61%. Indian cities do not use waste treatment and processing. Also organic matter found in Indian cities was found between 40-60% which could be recycled as compost. Most of the waste generally dumped or put into the low-lying areas devoid of any safety measures and operational control. Dumped MSW creates trouble for environment and human health. The relationship between MSW characterization and city population is given in Table 1.

Table 1. Characterization of MSW in India based on city population. [Source: CPCB,2010]

Item	<1 lacs 8 towns	1-5 lacs 11 towns	5-10 lacs 16 towns	10-20 lacs 13 towns	>20 lacs	Avg. %
Compostable	29.6-52	34.3-62.5	35.5-73	39.5-54.5	40.8-62.4	51.3

Recyclable	13.9-27.7	13.2-36.6	11.2-24.2	11-23.3	11.2-22.4	23.8
C:N ratio	17.7-35.6	14.1-36.9	17.7-52.6	18.6-52.2	21.4-43.3	33.3
HCV (kcal/kg)	1,234-3,414	591-3,766	591-2,391	804-2,762	834-2,632	2,179
Moisture	25-65	24-63	18-64	25-62	21-63	41

Capital city of India, Delhi generate approximately 7000-8000 tonnes of MSW per day. MSW of Delhi city constitutes about 54.42% organic matter capable of composting, 15.52% material capable of recycling and 30% inert materials on wet basis. Approximately, 400-450 tonnes forming about 5% of MSW generated per day is treated and preceded for composting and about 20% of MSW generallystay behind in open areas in Delhi that contributes to degradation of environmental health. There are three main sites in Delhi that are Okhla, Bhalswa and Gazipur. These sites collect per day 5700-6200 tonnes. There is two more landfill sites are also proposed for Delhi. Okhla landfill site have a incineration plant for waste to energy production. This plant intended to produce 16 MW of electrical energy by burning about 1350 tonnes of MSW per day (Table 2).

Table 2. State-wise MSW in India. [CPCB,2000]

State/UT	MSW (Tonnes/day)
Andhra Pradesh	3943
Assam	196
Bihar	1479
Delhi	4000
Gujarat	3805
Haryana	623
Himachal Pradesh	35
Karnataka	3118
Kerala	1220
Madhya Pradesh	2286
Maharashtra	8589
Manipur	40
Meghalaya	35
Mizoram	46
Orissa	646

Pondicherry	60
Punjab	1001
Rajasthan	1768
Tamil Nadu	5021
Tripura	33
Uttar Pradesh	5515
West Bengal	4475

12.6. Hazardous Waste

Hazardous wastes have properties of dangerous or potential to harm the human health and the environment. It may be liquids, solids, gases or semisolids like sludge. Collection, treatment and disposal of hazardous waste materials are known waste management. Most of the hazardous waste comes from chemical production, manufacturing and industrial activities. They have potential to harm during inadequate storage, transportation-waste storage or disposal. Environment Protection Agency (EPA) characterized four properties hazardous waste that are listed in the table below:

Table 3. Hazardous waste characteristics

Ignitability	Corrosivity	Reactivity	Toxicity
Liquids with a flash point–the lowest temperature at which fumes above waste ignite–of 60 ^{o}C. Examples- alcohol, gasoline, and acetone. Solids that spontaneously combust. Oxidizers and compressed gasses.	A corrosive is anything liquid with a pH of less than or equal to 2 or greater than or equal to 12.5, or has the ability to corrode steel. Corrosive substances, such as HCl, HNO_3, and H_2SO_4, have the ability to cause the harmful for human/animals.	Reactive materials can identify on the basics of many conditions that make them reactive such as unstable, detonating, and explosive mixing with water.	Poisonous stuff causes a greater risk of environmental and human health damage. EPA listed 60 chemicals in the poisonous contaminants. These are also known as toxicity characteristics leaching procedure (TCLP)

12.6.1 Biomedical waste

Biomedical waste (BMW) is the hospital based waste which generates during diagnosis, treatment of human animals. It follows as common waste, segregation, storage, transport and treatment. But 10-25 % of BMW is hazardous in nature which requires special waste management practices. Most of the hazardous part contributes physical, chemical and microbiological substances of BMW. In India, BMW management rule 2016 established a wide guideline to management hospital waste. Biomedical waste classified in four group which are show in the **table 4** and four type bin/bag system applies in hospitals and each hospitals follows guideline of government. **Figure 2** can easily see in the hospitals. Incinerator, pyrolysis and deep burial are main practices that apply for disposal of the hazardous BMW. Non-hazardous BMW are autoclave/ hydroclaving, microwave for sterilize. Biomedical waste has potential to produce various kind of hazardous waste and some are listed below as:

a) Infectious waste

Bacteria, viruses, fungi, and parasites are main living organism in the hospital waste and their concentration the waste materials sufficient to cause disease in the susceptible hosts. Pathological waste, cultures are main source of infectious waste because treatment process of human/animal requires some kind of samples that taken directly or indirectly from the body. These samples can be in the form of body fluids.

b) Medical equipment

They contacts during the treatment of disease and get infects from the respective disease. Such as hepatitis-c, HIV, cancer, and many other diseases needs separate medical equipments (knives, blades, syringes, needles, etc.).

c) Pathological waste

It includes tissue, human/animal organs, human fetuses, body parts, blood samples, etc. Recently COVID-19 pandemic caused by corona virus also spreads by means of pathogenic waste. Pathological waste arisen during this pandemic comprised of all disposable items associated directly or indirectly with COVID-19 infected patients. Few of them are listed as gloves, masks, blood contaminated items, plastic tubing, protective equipments, licked disposables, dressing materials, swabs, bandages, cotton, absorbed blood and bodily fluids, needles, syringes, etc. There are three major

routes for this viral infection including droplets transmission, contact transmission, and aerosol transmission. The first and the foremost rapid infection route is through droplets transmission that take place on coughing or sneezing of infected person. Any healthy person in proximity of above said respiratory droplets, produced from an infected person can get infection by ingestion or inhalation and suffer from the same deadly viral disease. The other route of infection i.e. contact transmission can be understood from its name as it occurs when anybody free from infection comes in contact with an infected surface or touches an object contaminated with the virus along with consequently touch his nose, mouth or eyes and get in to the virus trap. One more route of infection occurs via aerosol transmission that may results when an infected person cough and sneezes in the air and subsequently his respiratory droplets persists and get mixed into the air thereby forming aerosol molecules which may cause infection within fourteen days when inhaled high dose of aerosols concentrated into the lungs in a in comparison to outer environment. It is said that the incubation period of corona virus is about fourteen days. Waste generated through hospitals, quarantine wards, and laboratories impose a burden on land in the form of solid waste if not managed properly. Some of the liquid waste generated from laboratories and hospitals if disposed off as runoffs into water bodies may lead to severe contamination of water as well as organisms thriving there. Solid waste generation and waste water contamination from infected pathological waste may offer a variety of COVID-19 infection transmission routes in a rapid way if left unmanaged and untreated.

d) Pharmaceutical waste

It includes various waste materials that have toxic chemicals such as expired drugs, vaccines, serum, etc. This type waste requires dispose by the suitable methods.

e) Genotoxic waste

This types of waste includes mutagenic, teragetic and carcinogenic in nature. Vomit, feces of patients, urine are some examples that affect by special kind of drugs and radioactive materials

f) Heavy metal waste

Various heavy metals use in several types of medial equipments that are responsible for heavy metal contamination in the environment. Use of mercury in thermometers, blood pressure gauges, lead in radiation proofing are some examples can be subgroups of hazardous chemical waste.

g) Chemical waste

Many toxic, corrosive, inflammable and reactive chemicals use in clinical applications that considers as hazardous nature.

h) Radioactive Waste

The use of radioactive materials in the clinical studies is common in present time. Various radioisotopes uses in vitro analysis of body tissues and fluid, tumor localization, radiation therapy, x-ray and these medical techniques produces radioactive wastes.

Table 4. Biomedical waste classification

Category	Type of waste
Yellow	Dressing materials, cotton swabs, bandages, body fluids, blood bags, anatomical waste of human body, and body parts are to be discarded in yellow bags.
Red	Syringes devoid of needles, catheters, soiled gloves, In Vitro tubes etc. all are required to be disposed of in red colored bags. This kind of waste will will later be incinerated for disinfection.
Blue	Glass wares including Glass vials, ampoules are necessary to be discarded in a cardboard box of blue color or have a blue marking/sticker.
Black	Waste other than biomedical waste should be discarded into black bags. In hospitals, non-biomedical waste including vegetable and fruit peels, leftovers, kitchen waste, stationary, packaging including that from medicines, disposable caps, disposable masks, disposable tea cups, disposable shoe-covers, cartons, sweeping dust, etc.

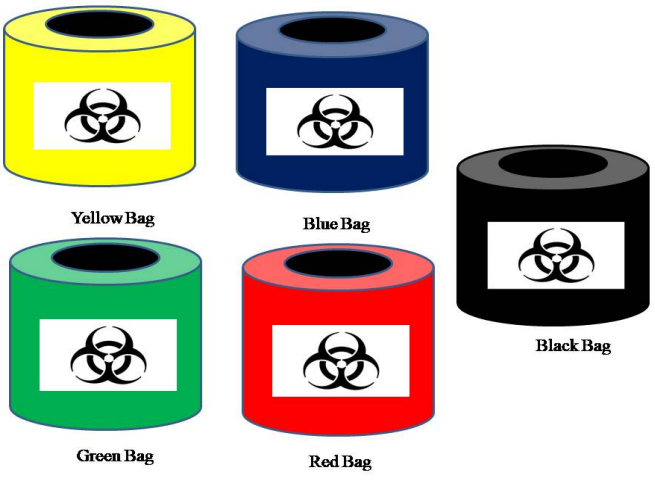


Figure 2. Biomedical waste management in India

12.6.2 Radioactive waste

Radioactive materials applications have been rapidly increasing throughout the world. Medical, biotechnology, energy are well known applications sectors of radioactive materials. These sectors creates a huge amount of radioactive waste especially energy sector where big amount of radioactive materials uses. Nuclear power plants considers as clean and green source of energy because of emission free-energy production. The rick of radioactive contaminants still serious concern and accidental leakage like Fukushima in 2011 (Japan), Chernobyl in 1986 (Russia) poses serious problems to biological systems as well as soil, water, air radioactive pollutions. Nuclear weapons also a threat for human race and their testing has received attention because these nuclear tests contaminate soil, water and air. Thus the disposal of nuclear waste requires strict guidelines. Nuclear waste commonly categorized into two groups: first low level radioactive waste and second high level radioactive waste. Radioactive waste comes from civilian activities such as hospitals, biotech research laboratories. These types of waste are mainly low level radioactive and low amount of waste. Whereas nuclear power plants, nuclear research centers for weapon produces high level radioactive waste in high amount.

Waste disposal is the end step of waste management and it comprises various norms and regulation. The radioactive waste isolates from human and environment. The safe disposal of radioactive waste requires that not leak in adverse climatic conditions such as flood, earthquake. Radioactive waste management involve many steps to clean the radioactivity, and these are steps are segregation, sorting, treatment, conditioning, storage, transport final disposal. Apart from this each radioactivity program requires waste minimization program so that intensity of waste reduce**. Table 5** Radioactive materials and their applications.

Table 5. Radioactive materials and their applications

Radioactive materials	Applications
Carbon-14	Radiocarbon dating
Cobalt-60	Cancer radiotherapy
Uranium	Nuclear fission; nuclear reactor: Nuclear fission reactors
Phosphorus-32	Identification of malignant tumours
Technetium-99	Radiographic scanning devices

12.6.3 Electronic waste

Electronic items such as mobile, TV, VCRs, stereos, computers, fax, photocopy machine are integral part of daily life. Each electronic itemhas a limited period of life and after this expires and useless. Many of these can reuse, refurbishes or recycles but most of expire items consider as waste. This is waste items called as electronic waste (e-waste). The term e-waste is applied for all type of consumer and business electronic equipments that are near or end of its useful life. Many components of electronic equipments contain materials that render them hazardous, depending on their condition and density, such as televisions and monitor has use cathode ray tubes that are consider as hazardous. Similarly, mobile phones, microwave and many other electronic types of equipment in build with various metallic substances that have potential to harm human/animal life. Therefore e-waste considers as hazardous waste but it depends on the types and nature of waste. The e-waste dispose by reduce, reuse and recycle concept.

SAQ 1

I. Match the most appropriate

Colour code	Type of waste
a. Yellow	i. Glass wares
b. Red	ii. Waste other than biomedical waste
c. Blue	iii. Dressing materials, body fluids, anatomical waste of human body blood bags
d. Black	iv. Syringes devoid of needles, catheters, soiled gloves

II. Answer the following questions

1. What do you understand by Radioactive waste?

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2. Define solid waste. Give its classification.

12.7. The solid waste problems

Poor MSW management practices are the serious matter for not only human health but also negative impact on environment. MSW contains heavy metallic substance that creates heavy metals problem in the vegetable and animal feeds. Biomedical waste disposal in inclinator create dioxins like carcinogens into the atmosphere. Hazardous chemicals from batteries, e-waste, radioactive materials are challenge for the complete disposal because most the available waste management technologies not fully ensure to leakage and radiation. Toxic materials and chemicals can leach or run-off to pollute the ground water table as well surrounding environment. Chemicals such as pesticides, herbicides contain various hazardous materials that can reach into food chain and biomagnifying process leads various problems for human and animal health. There are four major issues with MSW that are listed below:

12.7.1. Waste collection

MSW collection is quite challenging in the large cities and is done as a two-tier system including primary and then secondary collection. The foremost primary collection entails waste storage and transportation from the households at local waste collection points while the secondary part of waste collection from local points to the disposal or treatment site. This waste collection chain is too long and complex where leakage, segregation and breaking of transport services generally occurs from house of waste collect to disposal site.

12.7.2. Waste separation and recycling

MSW constitutes a complex mixture of organic, inorganic and recyclable waste. There is provision to choose organic, inorganic and recyclable waste in separate bags/bins likes hospitals in many cities. However lack of awareness people does not follow it and result is mix MSW which increases cost of recycling. Although recyclable part have revenue potential for rag picker that mainly seen on dumping site. Where, most of the recyclable waste separates by the help of rag pickers. If each part of MSW separates during initial collection point/house level a good quality of organic waste available for compost which another resource of MSW, similarly inorganic waste can be possible to dispose. Developed nations like USA, Germany, Sweden, and Japan have comprehensive utilization of resources by waste recycling. Developed nations still

suffers from proper waste recycling due lack of technological expertise and lack of awareness.

12.7.3 Incineration

It helps to reduce the volume of MSW and energy recovery, positive benefits. High cost and toxic emission of gases are main disadvantages of this technology. Moreover, large incinerator builds with flue gas cleaning systems, active carbon adsorption system and a bag house. These new generation incinerators are providing high efficiency of flue gas cleanup.

12.7.4. Landfill

Landfill sites or dumping sites of waste are major challenge in the waste management because landfill standards are not follows by many cities and some have not proper site of landfill. However, landfill sites acts like open dumping yards where MSW disposes and creates several problems for environment because many municipal corporation does not have landfill. Recovery gas is the composition of methane, carbon dioxide, sulphide however, global warming potential of methane 20% more than the carbon dioxide. Most of the site lack of recovery gas collection facility. Recovery gas from landfill site is source of energy but it depends on the nature of waste and their compositional ratio not uniform. Thus, it is not properly utilizes. Western countries recovered 60% recovery gas from landfill sites and developing nation like China only develops 20% recovery gas collection capability. Major issue with leachate that disposes in the sewage or leaches into ground water where it contaminates ground water. Open dumping sites attract birds for their feeds, and create problems for aircrafts. Thus, the standard of landfill sites is very sophisticated and requires attention in urban areas.

12.7.5 Practices to reduce solid waste

- Use of cloth or jute bag when you go shopping.
- Say no to plastic/polyethylene bags.
- Minimize the use of paper bags.
- Segregate of house-waste so that organic and inorganic garbage separate and biodegradable and non-biodegradable waste can dispose to respective methods.
- Do not scatter the waste/litter on streets, drains or open spaces
- Collect waste at appropriate place

- Try to separate storage of organic and inorganic waste so that organic waste can utilize as compost
- Try to follow Reduce, Recycle and Reuse
- Create awareness among your locality/community
- Adopt waste reduction practices.

12.8. Management of Solid Waste

Solid waste management is defined as the detailed procedure for management of solid waste by involving a number of steps including collection, segregation and treatment of waste. The term MSW management offers a way to recycle waste materials that are unable to dispose off. As long as people have been living in settlements and residential areas, garbage or solid waste generation would not come to an end and has remain an issuethrought. Waste management is all about to reduce the use of resources and utilize them judiciously with the main aim of reduction in waste generation. Industrialization has brought many positive as well as negative outputs with solid waste generation as negative one.

According to Britannica, "Solid-waste management, the collecting, treating, and disposing of solid material that is discarded because it has served its purpose or is no longer useful. Improper disposal of municipal solid waste can create unsanitary conditions, and these conditions in turn can lead to pollution of the environment and to outbreaks of vector-borne disease—that is, diseases spread by rodents and insects."

Waste management practices in India are not mature as developed countries such as USA, Japan UK. The present waste management techniques are insufficient to provide absolute solutions to the waste generation ratein the India. MSW is the mixture of many components that the given in the **Table 6.** Therefore, the many practices and technologies involve in the MSW management. MSW management practices are based on the types, quantity, quality, economic conditions, and environmental standards. **Figure3.**shows flow chart for MSW management. In this flow chart can be understand that the segregation is fundamental step for management of MSW.

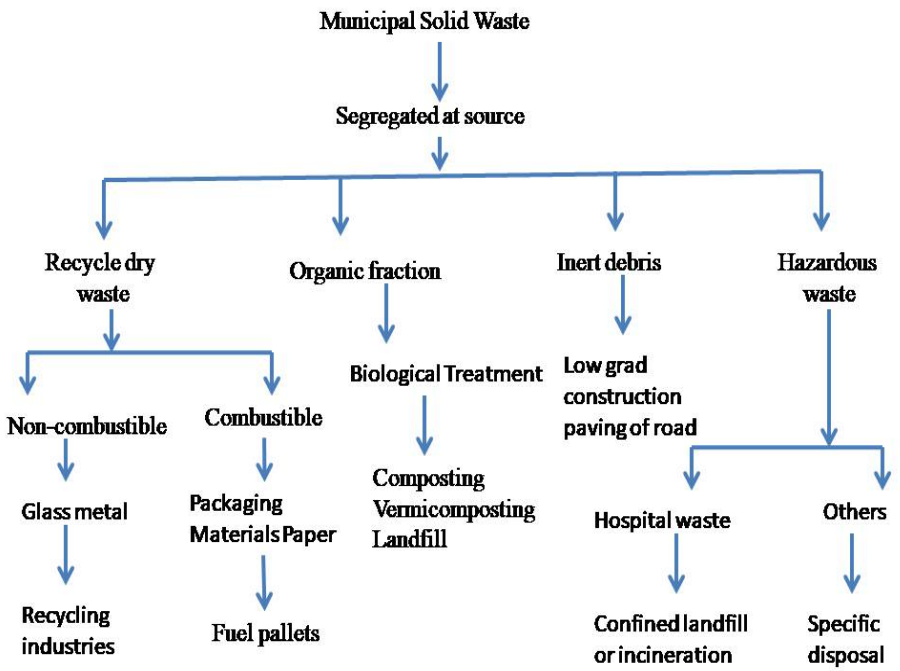

Figure 3. A flow chart for MSW management

Table 6. Management of solid mixture	
Component	**Material**
Compostable	Food waste, landscape, tree trimmings, etc.
Recyclables	Papers, plastics, glasses, metals, etc.
Inerts	Stones and silt, inorganic material, etc.
Toxic substances	Paints, pesticides, used batteries, medicines, etc.

12.8.1 Composting

This is most common technology in India. It involves a process of biological degradation in which oxygen leads to organic decomposition into carbon dioxide and compost. Biogas production is an alternative method, which has been successfully used in India in many rural areas. Composting can be divided into two parts: anaerobic digestion and vermicomposting/vermiculture.

(a) Anaerobic digestion/ biomethanation process is treat the solid waste and produce methane gas which utilizes as fuel. In this process most of the organic solid waste materials is to treat and methane gas production is energy recovery from solid waste. Digested solid matter utilizes fertilizer in agriculture field because it has many nutrient values such as organic carbon, mineral ions, microbial population, etc. Sewage sludge of wastewater treatment plants another can also be decomposed by anaerobic digestion. Sewage sludge has most of the portion of organic material. **Figure4. Anaerobic digestion of organic waste materials for biogas production.**

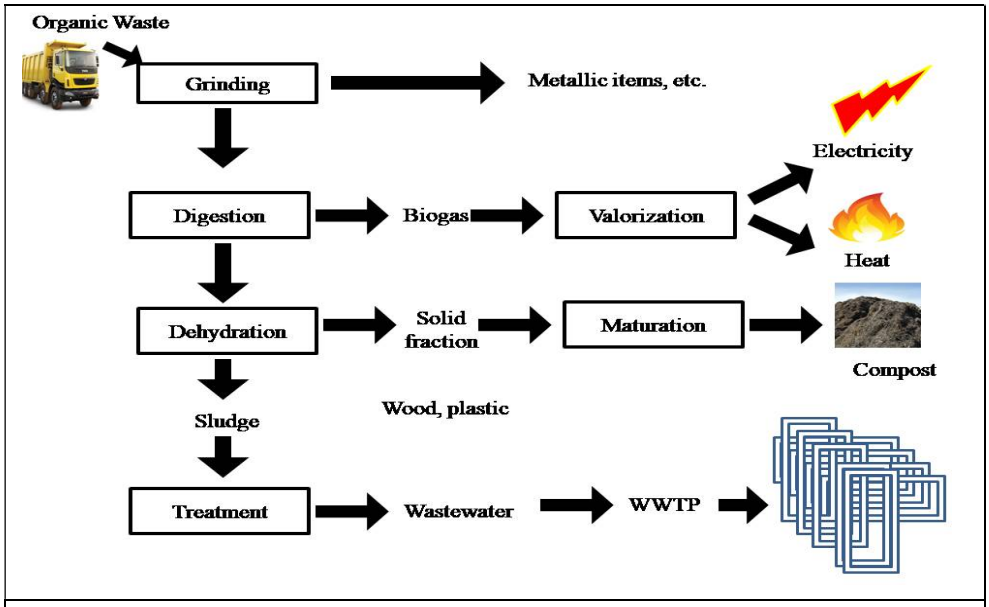

Figure 4. Anaerobic digestion of organic waste materials for biogas production.

The anaerobic digestion process consists of five phase as:

(i)Pretreatment and segregation

(ii) Anaerobic digestion

(iii) Recovery or organic manure

(iv) Effluent treatment and disposal and

(v) Power generation

(b). Vermicomposting/vermiculture is another bio-techniques for conversing the solid wastes such as sewage sludge, domestic waste or agriculture waste into

compost. In this technique, earthworms and microorganism are used for conversion of organic waste into compost materials. **Figure5.** shows a vermicompost diagram.

➢

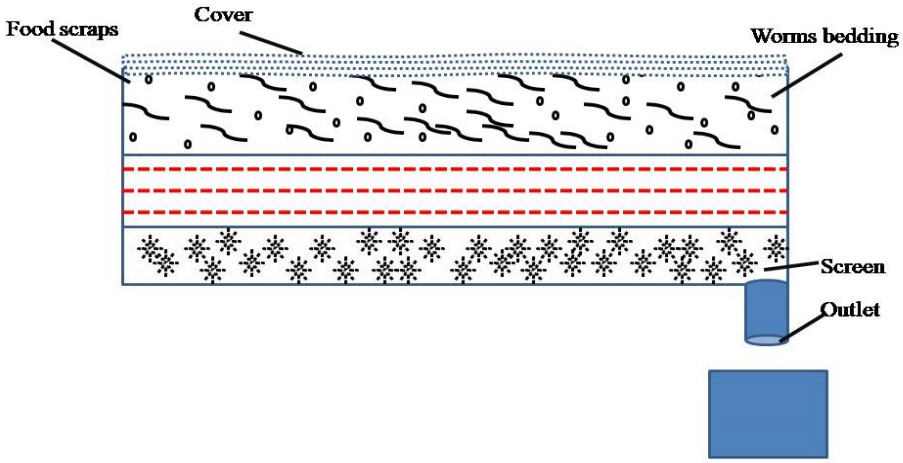

Figure 5. Vermicomposting diagram

12.8.2 Landfilling

Dump is one of the methods of handling urban garbage. Landfilling is a process in which collected solid waste materials directly dumped in a place. This method use for removal of components for composting or recycling or it may also be used for disposal of ash after an incineration process. Gazipur is one of the famous damping sites of Delhi for their garbage hill. Most of dumping sites situated from a long distance of urban population. These dumping sites are contains organic materials such as food wastes, wood, paper and fiber. This organic material is degrades by the action of microbial activities and creates many gases which are responsible for unpleasant smell. Methane, carbon dioxide, hydrogen are the well known gases emission of dumping site. **Figure 6. shows a dumping site.**

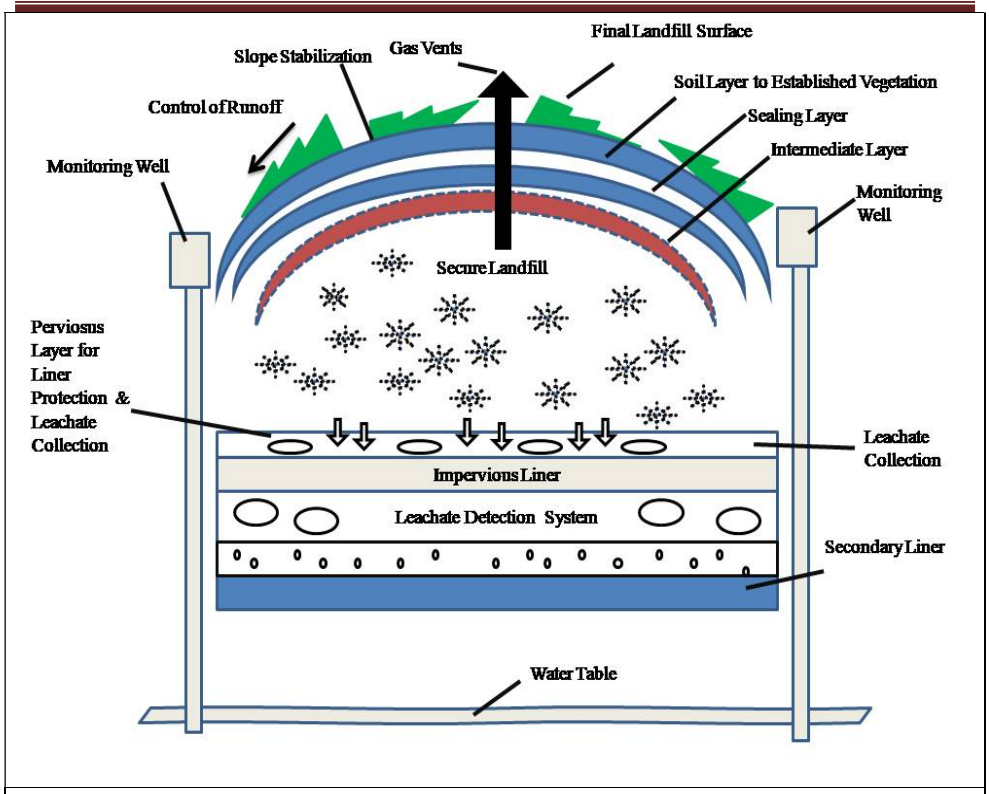

Figure 6. Landfill site

12.8.3 Incineration

This is an industrial method that applied for disposal of industrial waste**.** In this method, unwanted materials which are toxic solid waste can refuge in the incinerator. It leads to reduction of solid waste by volumeup to 70-90% and disposal of waste very fast as compare to compositing and landfilling. It also eliminates the problems associated with generation of methane and leachate which is main problem with landfill and composting methods. Incineration carries high temperature about 750-1000^{o}C and can be coupled with steam and electricity generation process. Incinerator converts solid waste into liquid and then gaseous form the releases it into the atmosphere, generating toxic chemicals such as dioxins and furans. The ash is the end product of incinerator which dumps in the landfill site. Incinerator is also work as energy recovery systems where thermal/electrical energy can be produce. Ash and chemicals have carcinogenic properties that create other problems for the environment. Incineration technique emits a number of air contaminants such asNOx, SOxand COx that lead toair pollutions and health hazard. Therefore incineration has many disadvantages.

The first incineration plant for MSW treatment was made in Delhi at Timarpur in 1987 with the capability of 300 tonnes/day and expenditure of Rs. 250 million by the help of

Denmark government. Due to poor performance, the plant was shut down after 6 month of operations. For institutional waste disposal, one more incineration plant was preparedat BARC, Trambay (Mumbai) which incinerate most of the paper waste. Apart from this, incinerator fundamental disposal system for biomedical waste where waste requires immediate solutions. Therefore, hospitals widely adopted this technology to dispose the biomedical waste.

Incinerator is commonly three types:

(i) Municipal waste incinerators

(ii) Hazardous (industrial) waste incinerator

(iii) Medical waste incinerator

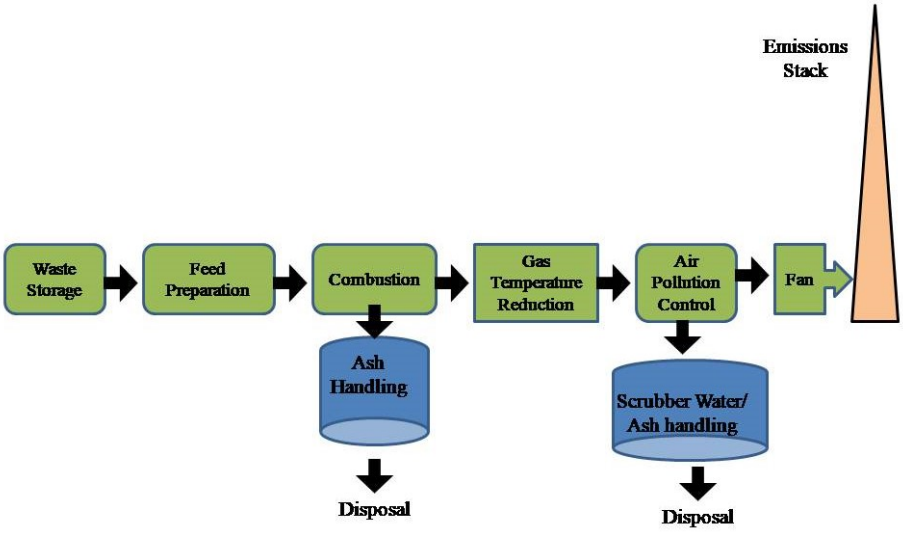

Figure 7. Incineration process.

12.8.4 Gasification/Pyrolysis

Gasification/Pyrolysis refers to high temperature waste treatment techniqueassociated with burning of waste under anaerobic or limited oxygenic conditions. It is similar to incinerator. Solid waste breaks into producer gas i.e. CO_2 and H_2O along with char. CO_2 and H_2O then undergo reduction by utilization of charcoal to produce CO and H_2. Gasification is also an energy recovery process which is produce energy by the combustion of solid waste materials. The combustible gas produces carbon monoxide, carbon dioxide, methane, hydrogen and water vapor, various intern gases present in the gasification agent, trace amounts of hydrocarbon, tar, ash, etc.

In India, two main gasifier designs are developed. NERIFIER gasification unit installed at Nohar, Hanungarh, Rajasthan developed by Narvreet Energy Research and Information (NERI) designed for combustion of a variety of waste from agricultural, forest and sawmill dust. This unit has 50-150 kg/h waste feeding rate capacity with 70-80% efficiency. One forth (25%) of fuel gas produced can be recycled back to support the gasification process and rest of the recovered for power generation. The second design developed by TERI which is installed at Gaul Pahari campus, New Delhi by Tata Energy Research Institute (TERI).

12.8.5 Refuse Derived Fuel (RDF)

This technology used for the conversion of MSW into pellets that another source of energy. Most of the RDF plants run in the southern Indian states such as Andhra Pradesh (Hyderabad, Guntur), Telangana (Vijaywada), Maharashtra (Mumbai), and Karnataka (Banglor). Hydrabad based RDF plant was installed in 1999, with 1000 tonnes/day capacity near dumping site. It produces about 210 tonnes/day pellets and stuff which utilizes for the power production (approximately 6 MW). In 1990, a RDF plant installed in Mumbai for the processing garbage into fuel pellets and this plant technology was indigenous technology, but this plant was shut down in last few years. A RDF plant was also established in Bangalore which had regular production of fuel pellets since 1989 with capacity of 50 tonnes/day of garbage and about 5 tonnes of fuel pellets produces for the gasification that can able to reduce the pollution as well as produce energy. These RDF reduces the load of landfill side because most of the MSW reuse for the energy production and return to landfill site in the form of ash. This ash has low volume which takes to small place for dump. Combustion of RDF produces pellets by gasification process is beneficial way to reduce the pollution as well as production of energy can reduce the cost of operation of RDF plants.

12.8.6 Recovery of recyclable materials

MSW is the complex mixture of various waste materials of urban area which is rich in recyclable materials such as paper, glass, plastic, rubber, metallic items, etc. Approximately 13 to 20 % content of various waste materials are recyclable and reusable in Indian cities and example of this Mumbai-17%, Delhi-15% of MSW can be recyclables. In this process, rag pickers are key players and they collets recyclable materials from streets, bins and dumping sites. Recycle of waste materials creates

livelihood in the life of rag picker. Most of the recyclable materials come from plastic and metals wastes, 40-80% of plastic waste recycled from developing nations compared to 10-15% in developed nations. Recovery rate of paper waste was 14% of total consumption 1991, while the global recovery rate was 37%. This is informal revenue generation area. About 100000 rag pickers exits in the Delhi city and they collect 10-15 kg materials per day, 17% Delhi's waste is handle by rag picker free of cost and about save big amount of money of government that is Rs. 600000 per day. Similarly, Pune, Mumbai, Bangalore like metro cities save a great amount of money by the help rag picker and they get their livelihood from recyclable materials. Rag picker also reduces the load of segregation on dumping sites which can to reduce economic load as well as environment burdens.

12.8.7 Waste to Energy

The concept of waste to energy has broadly adopted in developed countries and successfully produces energy from waste. USA produced 394 trillion Btu of energy recovery from MSW generatedin 1990. Japan installed 102 waste incinerators for energy recovery in 1991. India also started various waste to energy production plant in cities like Delhi, Chennai, etc. **Table 7.** MSW management technologies involve in the waste to energy production.Each waste to energy production technology has its advantages and disadvantages which are summered in the **Table 8.**

Table 7. State-wise energy recovery potential of MSW in India.

State/UT	Energy recovery potential (MW)
Andhra Pradesh	107
Assam	6
Bihar	67
Chandigarh	5
Chhattisgarh	22
Delhi	111
Gujarat	98
Haryana	18
Himachal Pradesh	1
Jharkhand	8
Karnataka	125

Kerala	32
Madhya Pradesh	68
Maharashtra	250
Manipur	1.5
Meghalaya	1.5
Mizoram	1
Orissa	19
Pondicherry	2
Punjab	39
Rajasthan	53
Tamil Nadu	137
Tripura	1
Uttar Pradesh	154
Uttaranchal	4
West Bengal	126
Total	**1457**

Table 8. Advantages and disadvantages of different MSW management technologies

Technology	Advantages	Disadvantages
Anaerobic digestion	Small scale digester cab be use Environmental friendly Compact design work in small places Energy recovery is easy and slurry can use as fertilizer Odorless as well as free from fly menace	Only suitable for organic waste Needs waste segregation
Landfill gas recovery	Low cost Produced gas can use as power generation and thermal application Eco-friendly	Surface runoff courses problems during rainy season Chances of explosion due to unmanaged gas

		production Pre-treatment and upgradation cost of gas is high Large area requires
Incineration	On-site installation feature reduces transportation cost of waste High output capacity can use continuous production of energy and waste disposal Compact size requires less land area	Skilled personnel need Production of toxic gas into atmosphere High capital cost
Gasification/Pyrolysis	Generation ofgaseous fuel and fuel oil exhibits several applications Superior than incinerator because of less pollution	Moisture content reduce the energy production High cost

12.9. Summary

In this unit, we have learnt in detail about water pollution. So far you have learnt that:

- The "**solid waste**" can be defined as any waste mostly in solid form such as refuse, trash or garbage, discarded material, etc. generated from any household, agricultural, mining, industrial or commercial activities.
- Solid waste that generates in urban area is known as municipal solid waste (MSW) and its management is one among the most challenging environmental issues.
- Appropriate waste management and handling depends upon the nature and amount of solid waste.
- Collection, treatment and disposal of hazardous waste materials are known waste management. Most of the hazardous waste comes from chemical production, manufacturing and industrial activities. They have potential to harm during inadequate storage, transportation-waste storage or disposal.
- Nuclear waste commonly categorized into two groups: first low level radioactive waste and second high level radioactive waste. Radioactive waste comes from civilian activities such as hospitals, biotech research laboratories. These types of

waste are mainly low level radioactive and low amount of waste. Whereas nuclear power plants, nuclear research centers for weapon produces high level radioactive waste in high amount.

- Solid waste management is defined as the detailed procedure for management of solid waste by involving a number of steps including collection, segregation and treatment of waste.

Glossary

Solid waste	:	any waste mostly in solid form such as refuse, trash or garbage, discarded material, etc. generated from any household, agricultural, mining, industrial or commercial activities.
Municipal solid waste	:	Solid waste that generates in urban area
Composting	:	involves a process of biological degradation in which oxygen leads to organic decomposition into carbon dioxide and compost
Landfilling	:	It is a process in which collected solid waste materials directly dumped in a place.

1.12 Possible answers to SAQs

Match the following

Colour code ***Type of waste***

a	iii
b	iv
c	i
d	ii

Answer the following

1. Radioactive waste : Hint (See 1.7.2)

2. Solid waste: Hint (see 1.3)

Classification: Hint (see 1.3.1, 1.3.2)

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1.14 Suggested readings

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1.15 Terminal and Model Questions

Q.1.What is organic waste?
Q.2.What is composting?
Q.3.What is solid waste?
Q.4.What is e-waste?
Q.5. How you can produce energy from waste?
Q.6. Explain the landfill site for MSW.
Q.7. Discuss sources, composition and characterization of the solid waste
Q.8. What are the major solid waste problems?
Q.9. What is hazard waste?
Q.10. What is biomedical waste?
Q.11. What is radioactive waste?
Q. 12. Discuss management of solid waste system.