Energy, Ecology and Environment

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Preface

There was a time "Environmental Science" was taught only to students of life sciences or natural sciences. With the evolution of man, his relationship with nature drastically changed. There was a long resilience period when ecological processes could recover from threats of human development. However, environmental problems arose with the multi-dimensional development of our society. Recent phenomenon of "climate change" surpassed all other threats imposed on human life and its sustainability. Therefore, today it has become the need of every citizen to know about the fundamentals of environmental science and its management.

Current scope of environmental science includes a wide range of subjects, viz., environmental sociology, environmental politics, environmental economics as well as **environmental engineering**. It is important for a student of engineering to know the deep relationship between environment and engineering. To use his / her skills in environmental management, it becomes mandatory for a student to know the interactions amongst physics, chemistry and biology of atmosphere, hydrosphere, lithosphere and biosphere.

The contents of this book primarily written for engineering students offer basic knowledge on energy resources and their management. It describes the problems related with air pollution and its management. There is a detailed description of issues related with water and waste water treatment. Other problems viz. noise pollution, soil pollution and solid waste pollution have also been described with a proper selection of case studies. I believe this knowledge on environmental science will help the engineering students in developing their professional skills.

Although, the content and accuracy of the text of this book are the responsibility of the author, I have realized that it would have never seen the light of the day without the dedicated work of my sincere friends and students. I thank my wife Usha, for providing me emotional base and companionship. My children Sushmit, Shilpa, Shitij and grandson Avya deserve a special thanks for their patience and cooperation. Finally, I thank the management of I.K. International, New Delhi for giving the present shape to this book.

S.V.S. RANA

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Energy and Environment

INTRODUCTION

Anybody can ask a question—*what is environment*? Einstein once defined environment as "**everything that is not me**". In other words we can say that "final analysis of everything present outside an individual is called environment". This outside world in which we all live, being a part of it, is cosmos. The cosmos has air, water, soil, sun, moon and other planets. It has plants, animals, rivers, mountains, deserts and oceans. Collectively they make nature. The nature to which we belong is our environment.

Another way of understanding environment is to classify it further as physical, chemical and biological environment. *Physical environment* includes radiation (light), temperature (heat), humidity and rain. *Chemical environment* has water, gases, acids, bases, inorganic elements and organic substances. *Biological environment* covers all living organisms found on the earth. These can be bacteria, viruses, microbes, algae, fungi, herbs, shrubs, crops, large trees, worms, insects, fish, snakes and mammals. The living world on the planet earth is supported by complex but interdependent physical, chemical and biological processes. These processes collectively result into evolution. Thus we find that in environment every thing is related with everything.

What is environmental science? Environmental science is a collective study of many subjects. It includes elements of agronomy (soil science), biology, botany, chemistry, climatology, ecology, entomology, geography, geology, hydrology, limnology, meteorology, oceanography, political science, psychology,

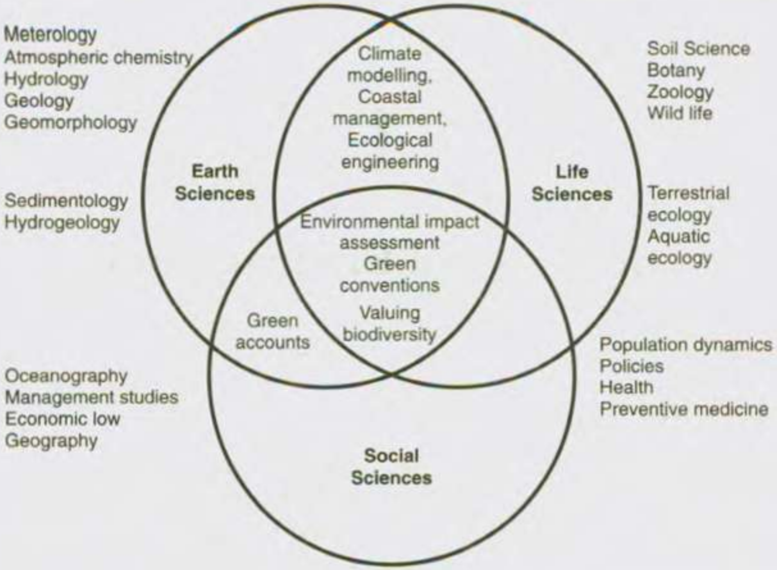

Figure 1.1 : *Scope of environmental science*

zoology, medicine and human and animal health. It also draws upon some specialized subjects such as biogeography, demography, economics, and toxicology. Thus, environmental studies constitute a multidisciplinary subject (Fig. 1.1).

Briefly, the environment has four realms *i.e.* **atmosphere, biosphere, lithosphere and hydrosphere**. Atmosphere is the gaseous envelope held by the gravitational force around the earth. Biosphere is concentrated mainly on the surface of earth. It includes all living species (individuals). Hydrosphere is the water domain. It includes all lakes, ponds, rivers, streams, estuaries, bays, oceans and sea. Earth's outer crust is lithosphere. These four realms are so closely related with each other that they cannot be separated absolutely. They interact with each other and make a **life supporting system**.

Man, biologically called *Homo sapiens sapiens,* evolved with other creatures. For a long period he remained a part of natural system. Then he started making tools, invented fire, grew agricultural crops and domesticated animals. Later developments changed agricultural man into an industrial man. He started using nature and its resources according to his demands. He made changes in all the four realms of environment. The part of the environment, which is directly affected by human expression of thought and action, now makes the fifth realm called ***homosphere*** *or* ***noosphere***.

If we look to the history, 16th and 17th centuries were a period of discovery. Living creatures were classified in 18th century. Nineteenth century debated on origin of life. In 20th century scientists connected organisms to their habitats. From 1930s to 1960s the modern discipline of ecology was born. Later part of 20th century witnessed the explosive growth of pure and applied environmental science. *Why*? It was the period that brought pollution, acid rain, loss of biological diversity, increased incidents of drought, famine, floods, health problems and above all a sense of insecurity. Technology worked as a double-edged sword. It brought revolutions in all major sectors but degraded natural systems and their occupants. Environmental science then emerged as wider field than ecology. ***It studies the secrets of natural world and suggests the ways and means to establish a balance between man and nature and its resources.***

In recent years, consciousness towards environmental issues has increased. Laws for environmental protection have been enacted in several countries. The credit for creating awareness goes to the conference on "Human Environment", held at Stockholm in 1972. Earth summit, another conference on environment, was held in Rio-De-Janeiro in Brazil in 1992. Important issues like human population explosion, conservation of biodiversity, protection of ozone umbrella and restoration of climate change were discussed. Efforts are being made to educate people on environmental problems and their management. Man has started to realize that environmental protection is his moral responsibility. Ethics thus developed are called environmental ethics.

ENERGY: BASIC CONCEPTS

Energy is most commonly defined as the equivalent of, or capacity for, doing work. According to the *Encyclopedia Britannica*, energy can either be associated with a material body, as in a coiled spring or a moving object, or it can be independent of matter, as light and other electromagnetic radiation passing through vacuum. The different forms of energy are gravitational, kinetic, heat, elastic, electrical, chemical, radiant, nuclear, and mass energy.

Energy is expressed in work units such as foot-pounds, joules, ergs, British thermal units (BTUs), kilowatt-hours (kWh), or tons of TNT-equivalent explosive energy. The energy content of various fuels that produce heat or electricity is generally measured in joules or BTUs. Comparative reserves of energy resources (such as natural gas, coal and petroleum) are often expressed as barrels of oil equivalent (bbl).

In the International System of units (SI), the preferred term for heat is the joule, where 1 J is the amount of work required to move a weight of 1 g through 1 cm ($1\ J = 10^7$ erg = 0.2381 calories). Alternatively, a BTU is the quantity of heat required to raise the temperature of one pound of water one degree Fahrenheit near the point of maximum water density (39.1°F). One BTU is equal to 1,055 joules. An appropriate unit for expressing the quantities of energy in world fuel reserves is the Q unit, which is equal to 101 BTUs.

Although the early Greek philosophers recognized fire as one of the primary elements (along with air, water, and earth), the concept of energy was first recognized by **Galileo** in the 17th century. Since energy itself is invisible—one cannot see heat or electricity—it is measured in terms of work that can be done or variations in heat content. Galileo discovered that, when a weight is lifted with a pulley system, the force applied multiplied by the distance through which that force must be applied (**the work**) remains constant even though either factor may vary.

Until the 19th century, human use of energy resources was limited to burning combustibles (wood and coal) for heating and cooking, burning oils made from plants and animal fats for lighting, and using water and wind to power simple machines to grind grain and pump water. Animal power was a significant part of the energy mix before the mid-20th century and remains so in many developing countries even today. Since the 1970s, water, wind, and the sun have become important sources of energy for electricity generation.

The development of theories of mechanics and thermodynamics by **Isaac Newton** and other physicists led to inventions like the steam engine, which uses energy to power machines to do work. The **Industrial Revolution** of the 18th and 19th centuries was driven by mechanical energy-using technologies. The drilling of the first oil well in 1869 in Titusville, Pennsylvania, and later the development of mass electricity distribution ushered in the age of energy, which has characterized the 20th century. Today, people in developed countries daily consume more than 100 times the energy used by primitive human beings (Table 1.1).

Table 1.1 : *Human energy consumption throughout history—daily per capita consumption (1000 kilocalories)*

	Food	Residential and commercial	Industry and agriculture	Transportation	Total
Primitive man	2	–	–	–	2
Hunting man	3	2	–	–	5
Primitive agricultural man	4	4	4	–	12
Advanced agricultural man	6	12	7	1	26
Industrial man	7	32	24	14	77
Technological man	10	66	91	63	230

Source: Cook (1971) and Loftness (1978).

Energy consumption represents six stages of human development. *Primitive man,* about one million years ago, had only the energy content of the food he ate. *Hunting man,* who lived about 100,000 years ago, had more food and also used wood for heat and cooking. About 5000 BC, *primitive agricultural man* grew crops and used animals for cultivation. By AD 1400, *advanced agricultural man* in Europe used coal for heating and also used water and wind for power. In the 19th century, *industrial man* added the steam engine as a source of mechanical energy. *Modern technological man* utilizes the internal combustion engine, steam turbines, gas turbines and electricity as his sources of energy.

The concept of energy is somewhat abstract; you can't see it or feel it, even though you have to pay for it. To understand energy it is easiest to begin with the idea of ***force***. We all have had the experience of exerting force-of pushing or pulling. The strength of a force can be measured by how much it accelerates

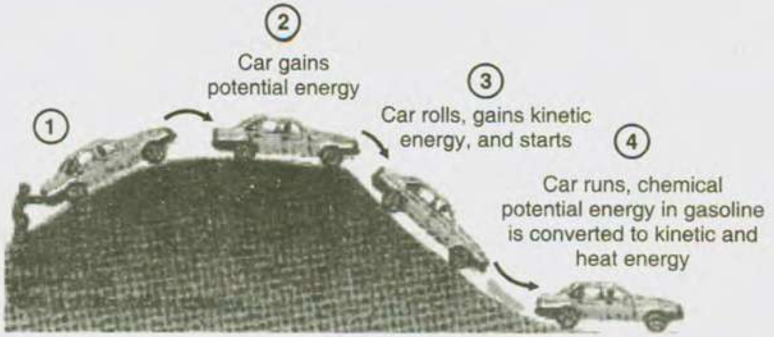

Figure 1.2 : *Some basic energy concepts, including potential energy, kinetic energy, and heat energy*

an object. Suppose that your car stalls while you are going up a hill and you get out to push it to the side of the road. You apply a force against gravity. If the brake is on, the brakes, tires, and bearings might heat up from friction. The longer the distance over which you exert the same force, the greater is the change in the car's speed, its position, or the heat in the brakes, tires, and bearings—that, in a physicist's terms, is the work done (Fig. 1.2). Work is exerting a force over a distance, that is, ***work is the product of force times distance*** **(conversely, it is often said that energy is the ability to do work)**. If you push hard, but the car doesn't move at all, you have exerted a force, but you have not done any work on the car (according to the definition), even if you feel tired and sweaty.

First Law of Thermodynamics

In pushing your stalled car, you have done three things: changed its speed, moved it against gravity, and heated its parts. These three things have something in common: They are all forms of energy. You have converted chemical energy in your body to the energy of motion of the car (kinetic energy), the gravitational (or potential) energy of the car, and heat energy. Energy can and often is converted or transformed from one kind to another, but the total energy is always conserved. **The principle that energy may not be created or destroyed but is always conserved is known as the first law of thermodynamics**. Thermodynamics is the science that keeps track of energy as it undergoes various transformations from one type to another. We use the first law to keep track of the quantity of energy.

Potential and Kinetic Energy

The conservation and conversion of energy can be illustrated by the example of a clock pendulum. When the pendulum is held in its highest position, it is neither moving nor getting hotter. It does, however, contain energy. We refer to the stored energy as ***potential energy***, which is converted to other forms when it is released. Other examples of potential energy are the gravitational energy in water behind a dam; chemical energy in coal, fuel oil, and gasoline, as well as in the fat in your body; and nuclear energy, which is related to the forces binding the nuclei of atoms.

When the pendulum is released, it moves downward. At the bottom of the swing the speed is greatest, and there is no potential energy. At this point all its energy is in the energy of motion, which is called ***kinetic energy***. As the pendulum swings back and forth, the energy changes continuously between potential and kinetic energy (Fig. 1.3). But at each cycle the pendulum slows down because of the friction of the pendulum

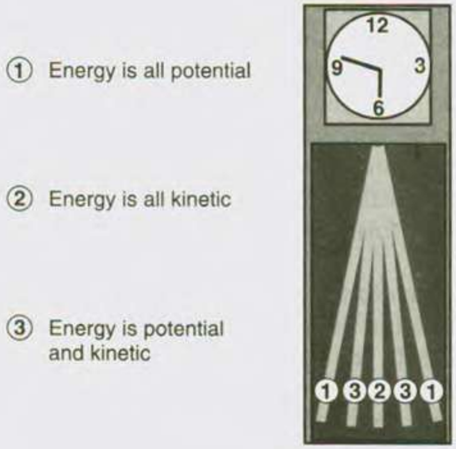

Figure 1.3 : *Idealized diagram of a pendulum clock illustrating the relation between potential and kinetic energy*

moving through air and the friction at its pivot. The friction generates heat. Eventually all the energy is converted to heat and the pendulum stops.

This example illustrates another property of energy—its tendency to dissipate and end up as heat. It is relatively easy to transform various forms of energy into low-grade heat, but difficult to change heat into high-grade energy. Physicists have found that it is possible to change all the gravitational energy in a pendulum to heat, but not to change all the heat energy (energy of random motion of atoms and molecules) thus generated back into potential energy.

Second Law of Thermodynamics

Energy is certainly conserved in the pendulum example; all the initial gravitational potential energy is transformed to heat when the pendulum finally stops. If the same amount of energy, in the form of heat, were returned to the pendulum, can we expect the pendulum to start again? The answer is NO! What, then, gets used up? It is not energy, because energy is always conserved. What gets used up is the **energy** quality, or the availability of the energy to perform work. The higher the quality of the energy, the more easily it can be converted to work; the lower the energy quality, the more difficult it is to convert to work. This example illustrates another fundamental property of energy: Energy always tends to go from a more usable (higher quality) form to a less usable (lower quality) form. This statement, the second law of thermodynamics, means that when you use energy, you lower its quality. Lower-quality energy is more difficult to utilize. When we use energy and it is converted to a less useful form, we say the entropy of the system has increased.

Let us return to the example of the stalled car, which you have now pushed to the side of the road. Having pushed the car a little way uphill, you have increased its potential energy. You can convert this to kinetic energy by letting it roll back downhill. You engage the gears to restart the car. As the car idles, the potential chemical energy to move the car (from the gasoline) is converted to waste heat energy and various amounts of other energy forms, including sound and electricity to charge the battery and play the radio.

According to the first law of thermodynamics, the total amount of energy is always conserved. If this is true, why should there ever be any energy problem? Why could we not collect that wasted heat and use it to run the engine? Here we discover the importance of the second law of thermodynamics. According to that law, energy used to move the car is degraded to low-quality heat, which can never regain its original availability or energy grade. When we refer to heat energy as low grade, we mean that relatively little of it is available to do useful work. High grade energy, such as gasoline, coal, or natural gas, has high potential to do useful work. The biosphere continuously receives high-grade energy from the sun and radiates low-grade heat to the depths of space.

ATMOSPHERIC ENERGY

Radiation

Basically all the energy that reaches the earth comes from the sun. The absorption and loss of radiant energy by the earth and the atmosphere are almost totally responsible for the earth's weather, both on a global and local scale. The average temperature on the earth remains fairly constant, indicating that the earth and the atmosphere on the whole lose as much energy by radiation back into space as is received by radiation from the sun. The accounting for the incoming and outgoing radiant energy constitutes the earth's **energy balance**. The atmosphere, though may appear to be transparent to radiation, plays a very important role in the energy balance of the earth. In fact, the atmosphere controls the amount of solar radiation that actually reaches the surface of the earth, and at the same time controls the amount of outgoing terrestrial radiation that escapes into space. In this section we consider, in particular, the role of the atmosphere in the earth's energy balance.

The intensity of radiation is measured by the amount of energy transferred per unit area per unit time (typical units are cal cm^{-2} min^{-1}). Although knowledge of the exact nature of all forms of radiation is incomplete, it is known that with respect to many properties, radiant energy acts as if it were transmitted in the form of waves. The wavelength λ and the frequency υ are related by $\upsilon = c/\lambda$, where c, the speed of light, is

2.998×10^{10} cm/sec. We will normally characterize radiation by its wavelength, measured in micrometers mm (10^{-4} cm) or angstroms A (10^{-8} cm).

Radiant energy, arranged in order of its wavelengths, is called the *spectrum* of radiation. The so-called electromagnetic spectrum is shown in Fig. 1.4. The sun radiates over the entire electromagnetic spectrum, though, as we will see, most of the energy is concentrated near the visible portion of the spectrum, the narrow band of wavelengths from 4000 to 7000 A.

Radiation is emitted when an electron drops to a lower level of energy. The difference in energy between the initial and final level, $\Delta\varepsilon$, is related to the frequency of the emitted radiation by Planck's law,

$$\Delta\varepsilon = h\upsilon = hc/\lambda$$

where $h = 6.63 \times 10^{-34}$ joule-sec. The electromagnetic wave emitted when an electron makes a transition between two energy levels is called a *photon*. When the energy difference $\Delta\varepsilon$ is large, the frequency of the emitted photon is high (very small wavelength) and the radiation is in the X-ray or gamma-ray region. The Planck condition also applies to the absorption of a photon of energy by a molecule. Thus, a molecule can absorb radiant energy only if the wavelength of the radiation corresponds to the difference between two of its energy levels. Since the spacing between energy levels is, in general, different for molecules of different composition and shape, the absorption of radiant energy by molecules of differing structure occurs in different regions of the electromagnetic spectrum.

The amount of energy radiated from a body depends largely on the temperature of the body. This maximum amount of radiation for a certain temperature is called the *blackbody radiation*. A body that radiates at a certain temperature is called a *blackbody*. This maximum is identical for every blackbody regardless of its constituency. Thus, the intensity of radiation emitted by a blackbody is a function only of the wavelength, absolute temperature, and surface area. The term "blackbody" has no reference to the color of the body. A blackbody can also be characterized by the property that all radiant energy reaching its surface is absorbed.

Electromagnetic Radiation

Planet Earth is bathed continuously in **electromagnetic radiation**, so named because this form of energy exhibits both electrical and magnetic properties. All known objects emit electromagnetic radiation Forms of electromagnetic radiation include radio waves, microwaves, visible light, infrared radiation,

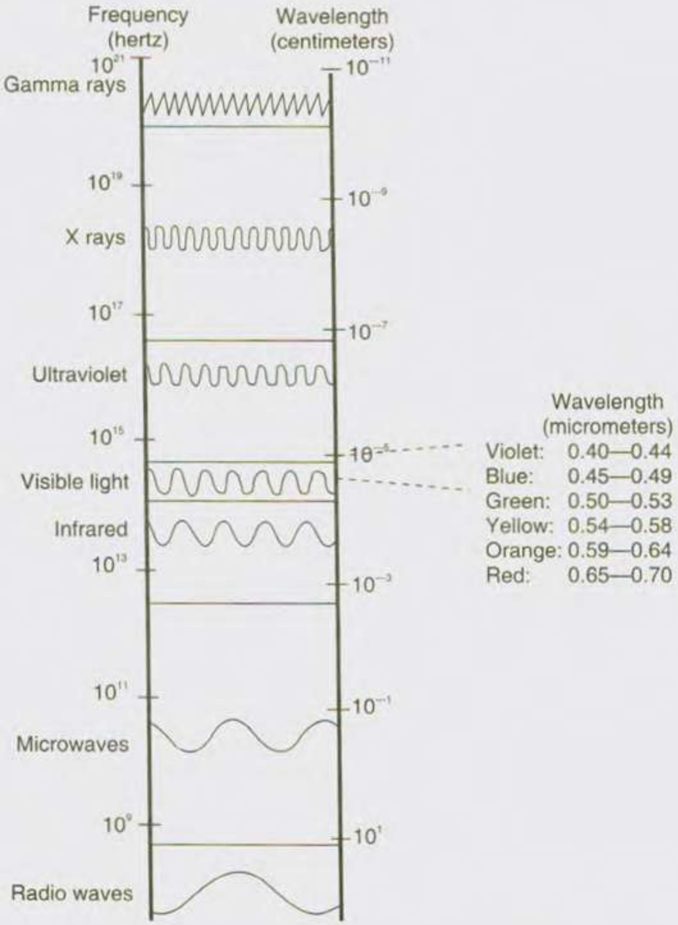

Figure 1.4 : *The electromagnetic spectrum consists of many types of radiation that are distinguished on the basis of wavelength, frequency, and energy level*

ultraviolet radiation, X rays, and gamma radiation. Together, all these forms of electromagnetic radiation make-up the **electromagnetic spectrum,** illustrated in Fig. 1.5.

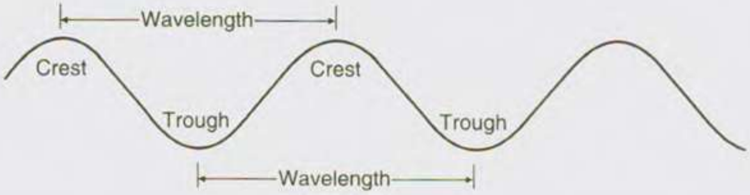

Figure 1.5 : *The wavelength of an electromagnetic wave is the distance between successive crests or, equivalently, the distance between successive troughs*

Electromagnetic radiation travels through space as well as through gases, liquids, and solids. In a vacuum, all electromagnetic waves travel at maximum speed, 300,000 km per second. All forms of electromagnetic radiation slow down when passing through materials, the speed varying with wavelength and type of material. As electromagnetic radiation passes from one medium to another, it may be reflected or refracted (that is, bent) at the boundary between the two media. This happens, for example, when solar radiation strikes the ocean surface: some is reflected and some is bent upon penetrating the water. Electromagnetic radiation can also be absorbed when solar radiation is absorbed at the Earth's surface and converted to heat.

Although the electromagnetic spectrum is continuous, different names are assigned to different segments because we detect, measure, generate, and use those segments in different ways. Note that the different types of electromagnetic radiation do not begin or end at precise points along the spectrum. For example, red light shades into invisible infrared radiation (infrared, meaning *below red)* on the frequency scale. At the other end of the visible portion of the electromagnetic spectrum, violet light shades into invisible ultraviolet radiation (ultraviolet, meaning *beyond violet*).

Infrared Radiation

Infrared radiation lies between microwaves and visible light. We cannot see infrared radiation, but we can feel the heat generated if the infrared radiation is intense enough, as it is, for example, when emitted by a hot stove. Some naturally occurring infrared radiation comes directly from the sun, but is converted by the Earth-atmosphere system from visible solar radiation.

At its uppermost frequencies, infrared radiation shades into the lowest frequency of visible radiation, red light. Wavelengths of **visible light** range from about 0.70 micrometer (μm) at the red end down to about 0.40 μm at the violet end of the spectrum. (A micrometer is a millionth of a meter.) Visible light is essential for photosynthesis and for many activities of plants and animals. For plants, the duration of sunlight coordinates flowering, the opening of buds, and the dropping of leaves. In some animals, the duration of sunlight regulates reproductive activity, hibernation and migration.

Beyond visible light on the electromagnetic spectrum and in order of increasing frequency, increasing energy level, and decreasing wavelength are **ultraviolet radiation (UV), X rays,** and **gamma radiation.** All three occur naturally, and all can be produced artificially. All have medical uses: ultraviolet radiation is a potent germicide; X rays are a powerful diagnostic tool; and both X rays and gamma radiation are used to treat cancer patients. These three highly energetic types of radiation can be dangerous as well as useful. Ultraviolet rays can cause blindness by irreparably damaging the retinal cells of the eye, and prolonged exposure to UV can cause cancer on exposed skin. Overexposure to X rays or gamma rays can cause sterilization, cancer, genetic mutations, and tissue damage to a fetus. Fortunately for us, the Earth's atmosphere blocks out most incoming ultraviolet radiation and virtually all X rays and gamma radiation. Without this protective atmospheric shield, all life on Earth would be quickly destroyed.

Microwave Radiation

Next comes the microwave portion of the electromagnetic spectrum, which has wavelengths ranging from 300 to

0.1 millimeter (mm). (A millimeter is a thousandth of a meter.) Some microwave frequencies are used for long-distance telephone communications, Earth-to-satellite television systems, tracking weather systems (radar), and in microwave ovens.

The biologic effect of microwave radiation (MWR) on organisms is a function of the water content, vascularity, and dielectric properties of tissues. Microwave energy converts into thermal energy during absorption by the tissues. It is the production of heat that results in tissue damage. There is non-uniform heat production following significant exposures. The non-uniformity results from the density differences between tissues, such as bone versus muscle. The rate at which energy is absorbed is the specific absorption rate (SAR). SAR is measured in watts per kilogram (W/kg). With these units, different substances and tissues can be categorized. Ten mW/cm^2 of energy increases body temperature to 1°C. The body absorbs approximately 60 Watts of energy. This is acceptable temperature elevation. The normal resting basal metabolism results in 1 to 1.3 W/kg. Two factors determine thermal dose: the peak tissue temperature and the duration that the temperature is maintained. The body's own thermoregulatory mechanisms modulate the increase.

The penetration of MWR increases with the length of microwave (Table 1.2). There are four general MWR bands (Table 1.3). These wavelengths range from television to cloud detection radar frequencies. There is overlap between these long waveforms of MWR and radiofrequency radiation (RFR) energy. The health effects tend to be similar. There are several known bio-effects reported from MWR (Table 1.4).

Table 1.2 : *Microwave penetration into tissues*

Band	Wavelength	Penetration
Super-high frequency	<0.03 m	Epidermis
Super-high frequency and ultra-high frequency	0.03-0.1 m	Subcutaneous
Ultra-high frequency and very high frequency	0.25-2 m	Through body

Table 1.3 : *Common uses of typical microwave frequencies*

Uses	Wavelength	Frequency	Band
Television	10-1 m	30-300 MHz	Very high frequency
Microwave ovens	1-0.1 m	0.3-3 GHz	Ultra-high frequency
Communications	10-0.01 m	3-30 GHz	Super-high frequency
Weather radar	0.01-0.001 m	30-30 GHz	Extra-high frequency

Table 1.4 : *Physiologic effects of microwave radiation on man and animals*

- Behavioral
- Cardiovascular
- Cataracts (human)
- Central nervous system disorders
- Circadian rhythms
- Developmental
- Environmental
- Genotoxic
- Hematologic
- Metabolic

Radio-Frequency Radiation

At the low-energy (low-frequency, long-wavelength) end of the electromagnetic spectrum are **radio** waves. Their wavelengths range from a small fraction of a centimeter to hundreds of kilometers, and their frequencies range up to a billion hertz. FM (frequency modulation) radio waves, for example, span 88 million Hz to 108 million Hz, hence the familiar 88 and 108 at opposite ends of the FM radio dial.

There has been a concern about radio-frequency radiation (RFR) since the late 1970s, when a report suggested that electromagnetic fields associated with power lines might increase the risk of childhood cancer. This allegation has spread from power lines to electric blankets, razors, computer terminals, hair dryers, and alarm clocks. The scare began after an individual gave his pregnant wife a cell phone in 1988. Two years later she developed a brain tumor adjacent to the area of the phone's antenna. This led to multiple lawsuits. Congressional hearings were held, while the Environmental Protection Agency (EPA), Food and Drug Administration (FDA), and national cancer institute all declared that there was no scientific evidence to support such claims. At present, there is no evidence that the use of mobile phones poses a direct health risk. In fact, an animal study looking at reproductive effects of the electromagnetic fields of mobile phones found that *in vitro* exposure to the radio-frequency field did not induce any measurable cognitive effects.

User surveys have suggested that digital phone users complain of discomfort, warmth, and picking on the ear during conversations. Others do not report an increase in symptoms either with controls or between digital and analog users. Although it has been suggested that there is a limited temperature increase in users, there is no evidence of permanent effects.

Cognitive effects have been alleged; however, this is not supported by the literature. In fact, there is evidence that use of mobile phones may increase cognitive abilities. This manifested as an apparent stronger association in choice reaction time in the analog group than the digital user group. This association has been supported in animal studies.

ENERGY RESOURCES

Energy can be defined as the capacity to do work. Work is the product of force. The agent used for "pushing or pulling" an object is called force. Thus energy is an abstract, concept. You cannot see it or feel it, even if you have to pay for it. It is an important factor in the development of an economy. The demand for energy has increased with the economic development of the world.

Energy consumption is an index of advancement of a country. In India the per capita energy consumption is only 221 kg of oil equivalent/year, a very low rate compared with other countries (Table 1.5).

Table 1.5 : *Energy consumption of some countries*

Countries	GNP	Koe
USA	19840	7655
Japan	21020	3306
Germany	18480	4421
China	330	580
India	340	221

Some of the energy resources are exhaustible or non-renewable e.g., coal and mineral oil, but many are renewable e.g., water and solar energy. Other non-conventional energy resources are bio-gas, wind, tidal and geothermal energy (Fig. 1.6).

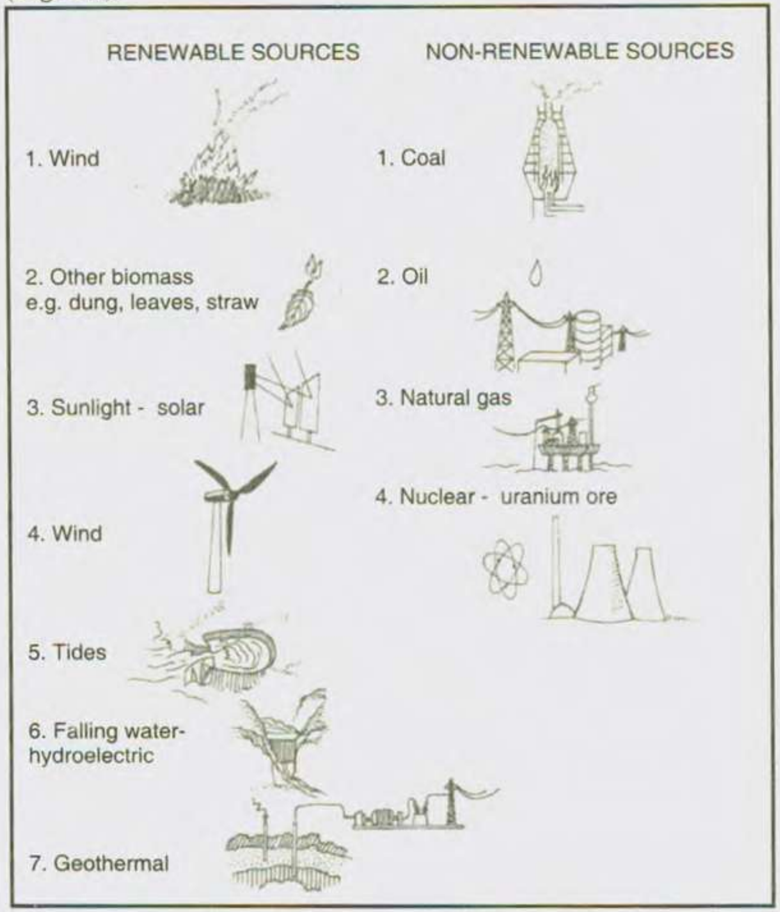

Figure 1.6 : *Sources of energy*

CONVENTIONAL OR NON-RENEWABLE SOURCES OF ENERGY

Fossil Fuels

Crude oil, natural gas, coal, oil shales and tar sands constitute the fossil fuels. They were created from incomplete biologic decomposition of dead organic matter; some organic matter was buried, escaped oxidation and was converted by complex chemical reactions in the geologic cycle to fossil fuel. Thus geologic cycle is responsible for the formation of fossil fuels. The fossil fuel resource is finite. Using even the most optimistic predictions, we can expect the total fossil fuel epoch in human history to be only about 500 years. The following table summarizes important information concerning the fossil fuels compared with other sources of energy.

Table 1.6 : *World proven reserves and annual use of fossil fuels*

		Reserves	
Region	**Petroleum (billion barrels)***	**Natural gas (Trillion ft 3)***	**Coal (billion tons)***
North America	75.7	291.4	285.2
South and Central America	89.5	219.1	23.8
Western Europe	18.9	161.5	99.7
Eastern Europe and Former USSR	58.9	1,999.4	288.4
Middle East	673.6	1,749.5	0.2
Africa	75.4	361.1	67.7
Far East and Oceania	43	359.6	322.3
Total	1,033.2	5,141.6	1,087.2
		Use	
	Petroleum	**Natural Gas**	**Coal**
World use, 1998*	26.6 billion barrels	83 trillion ft3	5.04 billion tons
World use, 1998 (quads Btus)	152 quads	85 quads	89 quads

* The fuels may be compared by calculating their energy content in British thermal units (Btus). One billion barrels of petroleum yields ca. 5.7 × 1015 Btus, or 5.7 quadrillion (quads) Btus. One trillion cubic feet of natural gas yields ca. 1.02 quadrillion Btus, and 1 billion tons of coal yields ca. 17.65 quadrillion Btus.

Source: Data from Oil and Gas journal and Energy Information Administration, US Department of Energy, 1999.

NON-CONVENTIONAL OR RENEWABLE SOURCES OF ENERGY

A. Direct Solar Energy

Broadly defined, solar energy includes a number of different energy sources, as shown in Fig. 1.7.

Active solar systems require mechanical power to circulate air, water or other fluids from solar collectors to a heat sink

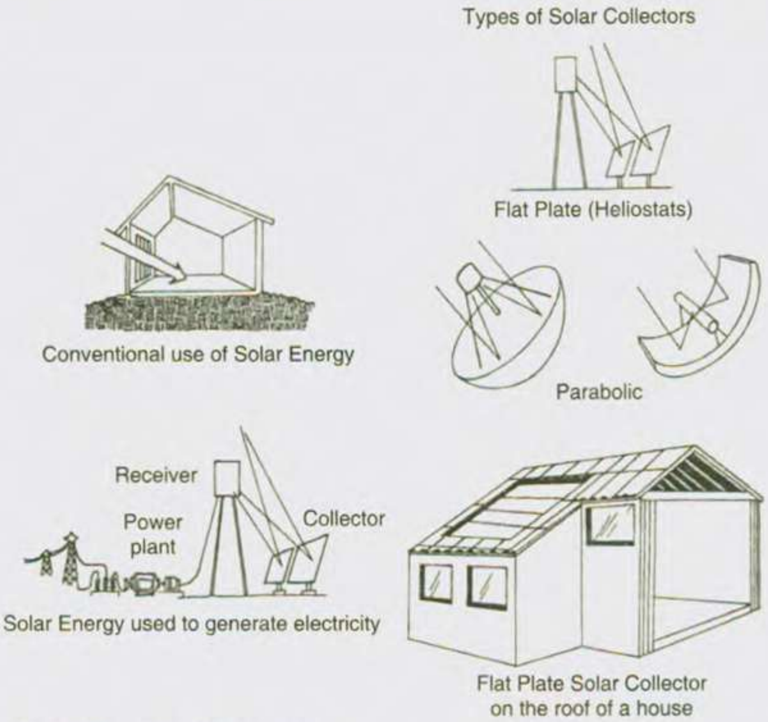

Figure 1.7 : *Uses of solar energy*

where the heat is stored until used. Solar collectors are usually flat panels consisting of a glass plate over a black background upon which water is circulated through tubes. These solar collectors act as greenhouses.

Passive solar systems often involve architectural design to enhance and take advantage of natural changes in solar energy that occur throughout the year without requiring mechanical power. Many homes throughout the world now use passive solar systems for at least part of their energy needs.

Another potentially important aspect of direct solar energy involves solar cells or photovoltaic that convert sunlight directly into electricity. Two other types of solar energy are the solar power tower and solar ponds.

India has been one of the major producers of photovoltaic (PV) systems. PV systems currently used include street lighting systems (SLS), domestic lighting systems (DLS), community lighting systems and TV (CDS and TV), water pumping systems and small power plants. The details of various solar photovoltaic systems installed are given below:

B. Wind Energy

Wind has propelled ships as well as driven wind mills used to grind grain and pump water. More recently, wind has been used to generate electricity.

In India, the significant achievements of the wind energy programme are indigenous development of wind pump and wind generators. Under the international cooperation programme, two wind farms of 10MW each in Tamil Nadu and Gujarat have been established with support from Danida of Denmark. The details of the wind energy systems installed so far are given in Table 1.7.

Table 1.7 : *Wind energy systems*

System	No. of systems installed
Wind pumps	2,540
Wind farms	12
Wind electric generators	28
Battery chargers	47

C. Hydropower

Early in technological history, it was discovered that the force of falling water could be used to turn paddle wheels, which in turn would drive machinery to grind grain, saw logs into lumber, and do other laborious tasks. The modern culmination of this use of water power or hydropower is huge hydroelectric dams, where water under high pressure flows through channels, driving turbogenerators. The amount of power generated is proportional to both the height of the water behind the dam, i.e., what provides the pressure, and the volume of water that flows through.

About 8.5% of the electrical power generated in the United States currently comes from hydroelectric dams; most of it from about 300 large dams concentrated in the Northwest and Southeast. Worldwide, hydroelectric dams have a generating capacity of 678,000 MW, with an additional 50,000 MW in the construction or planning stage. Hydropower generates 19% of electrical power throughout the world and is by far the most common form of renewable energy.

Environmental Effects of Hydropower

Although waterpower is basically a non-polluting, renewable source of energy, harnessing it by means of hydroelectric dams still involves high ecological, social, and cultural problems:

1. The reservoir created behind the dam inevitably drowns farmland or wildlife habitats and perhaps towns or land of historical, archaeological, or cultural value. Glen Canyon Dam (on the border between Arizona and Utah), for example, drowned one of the world's most spectacular canyons. Tehri dam in India drowned the entire old town of Tehri in Uttaranchal Pradesh (India).
2. Dams impede or prevent the migration of fish, even when fish ladders are provided. Federal surveys show that fish habitats are receding because of damming. Salmon fishing, one of the great industries of the Northwest, has been heavily affected by construction of dams.
3. Changing from a cold-flowing river to a warm-water reservoir can have unforeseen ecological consequences. The reservoir behind the Aswan High Dam in Egypt has fostered the spread of a parasitic worm *Schistisoma* that causes a debilitating schistisomiasis disease. The reservoir has also increased humidity over a widespread area, and the higher levels of humidity are now accelerating the deterioration of ancient monuments and artifacts that have stood virtually unchanged for many centuries.
4. Ecological consequences occur below the dam as well. Since the flow of water is regulated according to the need for power, dams play havoc downstream; water may go from near flood levels to virtual dryness and back to flood levels in a single day. Other ecological factors are also affected, because sediments with nutrients settle in the reservoir, so that smaller-than-normal amounts reach the river's mouth.

As these problems were not considered serious, thoughts of greatly expanding water power in the United States are nullified by the fact that few sites conducive to large dams remain. Already, 65,000 dams dot US rivers; only 2% of the nation's rivers remain free flowing, and many of these are now protected by the Wild and Scenic Rivers Act of 1968, a law that effectively gives certain scenic rivers the status of national parks.

In short, proposals for new dams in the United States and elsewhere are a subject of controversy over whether the projected benefits justify the ecological and sociological trade-offs. In 1997, the World Bank gave preliminary approval to a loan to the Laos People's Democratic Republic for construction of the Nam Theun Two Dam, a 680-MW project that is expected to help Laos begin a process of economic development. The World Bank's decision has come under fire because the project will displace 4,500 people and destroy 2,485 square miles of sensitive environments. Another huge dam under construction is the Three Gorges Dam on the Yangtze River in China. When completed, it will be the largest dam ever built, displacing some 1.9 million people in order to generate 18,200 MW of electricity.

Tehri Dam Conflict

The 260.5 metre high Tehri Dam on the Bhagirathi in the Garhwal-Himalayas is being publicized as one of the most promising projects—a symbol of the country's prosperity and prestige. It will bring prosperity by generating 2,400 MW peaking power, which according to the dam builders, will help in establishing 140 industrial cities such as Modinagar (near Delhi), providing 300 cusec of water to meet the water supply needs of Delhi and irrigating 2.7 lakh hectares of land in Western Uttar Pradesh. The project has generated controversy since its inception. In spite of objections of several scientists of national and international repute, the project is yet to be modified stopped accepted.

D. Tidal Energy

India has initiated the wave energy project off the Vizhinjam Fishing Harbour near Trivandrum. The effort is totally indigenous. On successful completion, it is expected that the device will generate 75 Kw power during April-November period, 25 Kw during December-March and 120 Kw during June-September with a peak of 150 Kw with an energy output of 4.45 lakh units/year. It operates on the principle of Oscillating water column.

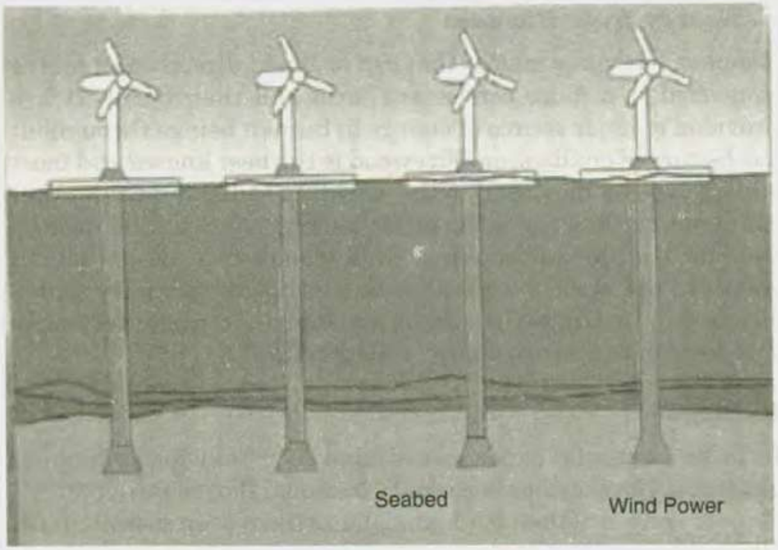

Figure 1.8 : *Wind blowing across the sea turns the windmill blades. The spinning blades power a machine called turbine inside the windmill, which produces electricity*

Using cold sea-bottom water and warm surface water, it is possible to harness energy. Such a programme is called *Ocean Thermal Energy Conversion* (OTEC). Ocean is a large collector of solar energy which is mainly responsible for generating currents. India will be deploying very soon a 1-Magawatt floating OTEC technology demonstration pilot plant, 60 km off Tuticorin in Tamil Nadu.

Wind blowing across the ocean surface produces *waves*. Ocean waves can be used to produce electrical energy. This is made possible using the temperature difference between warm surface water and cold deep water. A small wave energy plant has been installed at Vizhinjam in Kerala.

Sea level rises and falls mainly due to *gravitational attraction* of the Sun and the Moon. These are called *tides*. As a result, sea water gushes into rivers during low tide twice everyday. By constructing a dam, water can be stored during high tide, and on its flowing back to the ocean can be made to run turbines for producing electricity.

E. Energy from Biomass

Biomass is organic matter that can be burnt directly as a fuel or converted to a more convenient form and then burnt. It has provided a major source of energy to human beings throughout the history of civilization. Firewood is the best known and most widely used biomass fuel in the world. In India and a few other countries cattle dung is burnt for cooking. In Scotland, peat is used for heating and cooking. On a global scale, over 1 billion people in the world even today use wood as the primary source of energy. In US various biomass sources contribute nearly 2 percent of the entire energy consumption.

F. Biogas

In India successful experiments have been done for developing gobar-gas. Government launched a National Biogas Development Project and since then 6.5 lakhs plants have been installed (till 1987). They will meet the energy demands of farmers and will help in conserving the conventional sources of energy. China has also undertaken biogas development projects.

Biogas is rather a vague term used to represent the various compositions of different gases, which are produced as a result of action of anaerobic microorganisms on raw materials such as domestic and agricultural wastes generally within simple digesters (popularly known as biogas plants). Biogas contains methane in bulk and other gases like CO_2, H_2, N_2, O_2, etc.

G. Geothermal Energy

The idea of hares sings the Earth's internal heat is not new. As early as 1904, geothermal power utilizing dry steam was developed in Italy and natural internal heat is now being used to generate electricity in USSR, Japan, New Zealand, Iceland, Mexico and California.

Based on geologic criteria, several geothermal systems may be defined e.g., hydrothermal convection systems, hot igneous systems and geo-pressured systems.

H. Biodiesel

Biodiesel is the name for a variety of ester-based oxygenated fuels derived from natural, renewable biological sources such as vegetable oils. Biodiesel operates in compression ignition engines like petroleum diesel, thereby requiring no essential engine modifications. Moreover it can maintain the payload capacity and range of conventional diesel. Biodiesel fuel can be made from new or used vegetable oils and animal fats. Unlike fossil diesel, pure biodiesel is biodegradable, non-toxic and essentially free of sulphur and aromatics. The concept of using vegetable oil as a fuel dates back to 1895 when Dr. Rudolf Diesel developed the first diesel engine to run on vegetable oil.

Vegetable oils can be chemically reacted with an alcohol (methanol is the usual choice) to produce chemical compounds known as esters. Biodiesel is the name given to these esters when they are intended for use as fuel. Currently, biodiesel is produced by a process called transesterification where the vegetable oil or animal fat is first filtered and then processed with alkali to remove free fatty acids. It is then mixed with an alcohol (usually methanol) and a catalyst (usually sodium or potassium hydroxide). The oil's triglycerides react to form esters and glycerol, which are then separated from each other and purified. Much of the current interest in biodiesel production comes from soybean producers who faced problems like an excess of production capacity, product surpluses and declining prices. Methyl soyate or soydiesel made by reacting methanol with soyabean oil, is the main form of biodiesel in the United States. Waste animal fats and used frying oil (known as "fellow grease"), peanuts, cottonseed, sunflower seeds and canola are some of the potential feedstocks for biodiesel. Esters made from all the above feedstocks can be used successfully as automotive fuel, although they may differ slightly in terms of energy content, octane number and other physical properties.

Oil from rapeseed is also a raw material of choice for biodiesel production and is leading with a share of over 80% as a raw material source with highly suitable properties. Sunflower oil takes second place with over 10% share mostly in Italy and Southern France. Percentage share of some feedstocks for biodiesel in various countries is given in Table 1.8.

Table I.8 : *Feedstock for biodiesel in some countries*

Feedstock	% Share	Countries
Rapeseed	80%	
Sunflower	10%	Italy, Southern France
Soya bean		USA
Palm oil		Malaysia
Linseed and olive oil		Spain
Cotton seed oil		Greece
Jatropha curcas oil		Nicaragua
Beef tallow		Ireland
Used frying oil		Australia

The general process of biodiesel production is depicted in Fig. 1.1. A fat or oil is reacted with an alcohol (methanol) in the presence of a catalyst to produce glycerine and methyl esters or biodiesel. The methanol is charged in excess to assist in quick conversion and recovered for reuse. The catalyst is usually sodium or potassium hydroxide, which has already been mixed with the methanol.

NUCLEAR ENERGY AND ITS MANAGEMENT

Nuclear Energy

The first controlled nuclear fission demonstrated in 1942 led to the development of primary use of uranium-explosives and as a source of heat for generating electricity. One kg of uranium oxide produces a heat equivalent of approximately 16 metric tons of coal. It makes uranium an important source of energy throughout the world.

A. Uranium: There are two primary sources of uranium i.e., **pitchblende**, which has 50 to 80 per cent uranium content and uraninite that contains 60 to 80 per cent of uranium. Canada and United States of America are the leading uranium producers.

B. Thorium: Another source of nuclear energy is thorium. The major sources of thorium are **thorianite**, **allanite** and **monazite**.

Radioactive Wastes

To understand the problems surrounding nuclear waste disposal, we must understand the concept of radioactive decay. As unstable isotopes eject particles and radiation, they become stable and cease to be radioactive. This process is known as radioactive decay. As long as radioactive materials are kept isolated from humans and other organisms, the decay proceeds harmlessly.

The rate of radioactive decay is such that half of the starting amount of a given isotope will decay in a certain period of time. In the next equal period, half of the remainder (half of a half, which equals one-fourth of the original) decays, and so on. The time for half of the amount of a radioactive isotope to decay is known as the isotope's half-life. The half-life of an isotope is always the same, regardless of the starting amount.

Each particular radioactive isotope has a characteristic half-life. The half-lives of various isotopes range from a fraction of a second to many thousands of years. Uranium fissioning results in a heterogeneous mixture of radioisotopes, the most common of which are listed in Table 1.9. Some of this material—in particular, the remaining ^{235}U and plutonium e39pu that has been created by the neutron bombardment of ^{238}U—can be recovered and recycled for use as nuclear fuel. This operation is called reprocessing.

Disposal of Radioactive Waste

The development of, and commitment to, nuclear power went ahead without ever fully addressing the issue of ultimate long-term containment. Proponents of nuclear power generally assumed that the long-lived wastes could be solidified, placed in sealed containers, and buried in deep, stable rock formations (geologic burial) as the need for such containment became necessary. However, this has not yet happened. Thus, the current problem of nuclear waste disposal is two-fold:

- Short-term containment, to allow the radioactive decay of short-lived isotopes. In 10 years, fission wastes lose more than 97% of their radioactivity. Wastes can be handled much more easily and safely after this loss occurs.
- Long-term containment (EPA recommends a 10,000 year minimum, and the National Research Council opted for 100,000 years), to provide protection from the long-lived isotopes. Government standards require isolation for 20 half-lives. (Plutonium has a half-life of 24,000 years.)

Table 1.9 : *Common radioactive isotopes resulting from uranium fission and their half-lives*

Short-lived fission products	Half-life (days)
Strontium-89	50.5
Yttrium-91	58.5
Zirconium-95	64.0
Niobvium-95	35.0
Molybdenum-99	2.8
Ruthenium-103	39.4
Ioxine-131	8.1
Xenon-133	5.3
Barium-140	12.8
Cerium-141	32.5
Praseodymium-143	13.6
Beidtnuyn-147	11.1

Long-lived fission products	Half-life (years)
Krypton-85	10.7
Strontium-90	28.0
Ruthenium-106	1.0
Cesium-137	30.0
Cerium-144	0.8
Promethium-147	2.6

Additional products of neutron bombardment	Half-life (years)
Plutonium-239	24,000

For short-term containment, spent fuel is first stored in deep swimming pool-like tanks on the sites of nuclear power plants. The water in these tanks dissipates waste heat (which is still generated to some degree) and acts as a shield against radiation. The storage pools can typically accommodate 10 to 20 years of spent fuel. However, the capacity of storage pools at US nuclear plants reached 30% in 2000 and will be at 90% by 2012. After a few years of decay, the spent fuel may be placed in air-cooled dry casks in order to save space. The casks are engineered to resist floods, tornadoes, and extremes of temperature. Currently, 10 nuclear plants have turned to dry storage with the prospect of many more as pool storage capacity is exhausted.

In the meantime, the wastes from the world's commercial reactors have been accumulating at a rate of 10,000 tons a year, reaching 180,000 tons at the end of 2000, all of which is stored on-site at the power plants. Of these wastes, 41,000 tons are in the United States. Furthermore, because of neutron bombardment of the *reactor* walls, all nuclear power plants will eventually add to the stockpile of radioactive wastes. Scientists estimate that dismantling a decommissioned power plant will generate more nuclear waste than the plant produced during its active life.

STUDY QUESTIONS

1. Define the environment and discuss the scope of environmental science.
2. Explain with suitable examples the first and second law of thermodynamics.
3. What do you understand by energy resources?
4. Give a detailed account of renewable and non-renewable resources of energy.
5. Write short notes on the following:
   (a) Atmospheric energy
   (b) Electromagnetic radiation
   (c) Microwave radiations and their health effects
   (d) Bio-diesel
   (e) Nuclear energy and its management
   (f) Radio-frequency radiation.

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2

Global Environmental Problems

INTRODUCTION

Since the beginning of human civilization, mankind has lived in a competitive relationship with nature. His relentless pursuit of progress, comfort and security has resulted in increased stress on environment, particularly since the industrial revolution. Consequently, the life sustaining environment has been forced to transform more rapidly than ever before. Human tendency to exert a negative influence on ecology has resulted into rapid increase in the greenhouse gases in the atmosphere, large scale deforestation, loss of biodiversity, severe land degradation and environmental pollution. The effects of these problems are global, so we call them as **global environmental problems**. The overall impact of these problems has been observed as climate change, depletion of ozone, a rise in sea level, changes in agricultural output and loss of biodiversity, ultimately leading to an ecological crisis capable of affecting the entire life and life support systems existing on our planet, Earth. Problems of global warming, ozone depletion, loss of biodiversity, El-Nino and excessive generation of solid wastes are discussed below.

GLOBAL WARMING

In recent past, global observations have provided clear evidence of climatic changes resulting from anthropogenic activities. According to a report from World Watch Institute (1992), the earth's surface was warmest in 1990. Six of seven warmest years on record have occurred since 1980. Observations on temperature at many places of the world over the last century show an average increase of about 0.5^0K. This is supported by palaeo-climatic evidence gathered from deep-sea ice-cores in Arctic and Antarctic regions. While the primary cause of an increase in global temperature in the past has been increasing concentration of CO_2, fossil fuel burning, extensive deforestation, rapid increase in chlorofluorocarbons (CFCs) has further complicated the global environmental problems.

The minor gaseous constituents, more commonly known as trace gases or greenhouse gases (GHGs) like CO_2, ClO_2, CH_4, N_2O, HO_2, O_3 CFCs etc., though occur in traces but play a surprisingly dominant role in regulating the entire earth's atmosphere.

Greenhouse Effect

Greenhouse gases act as the glass pans of a greenhouse, which allow solar radiations to pass through and heat the surface of the earth but do not allow the heat radiated from the ground to pass through, thereby trapping it in the process. This heat trapping phenomenon is known as *greenhouse effect* (Fig. 2.1).

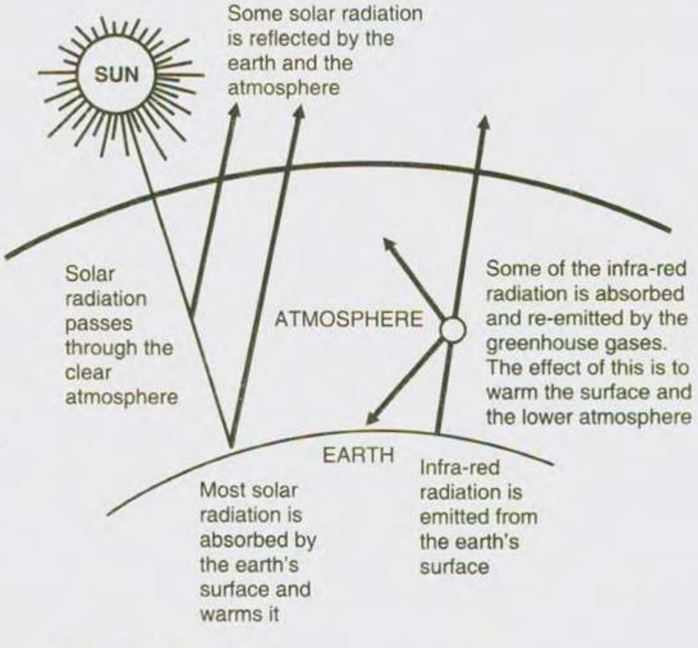


Figure 2.1: *Greenhouse effect*

Sources and Sinks of Greenhouse Gases

There are three main sources of greenhouse gases.

i. *Solar sources*—Changes in solar constant, x*UV* region, solar proton events and changes in ozone content generate the trace gases.

ii. *Volcanic sources*—Clx and a number of molecular species like CO_2, H_2, CH_4, COs are of greenhouse interest. Mt. Agung alone that erupted in 1963 spewed 3×10^{32} molecules.

iii. *Biospheric or industrial sources* — CO_2, N_2O, CH_4 and CFCs are derived from biospheric or industrial sources.

Table 2.1: *Greenhouse molecules*

Species		Mixing ratio		Recent rate of growth (%/yr)	Calculated life time	Ozone depletion potential*	HGWP**
	1979	1986	2050**				
CO_2	335.5 ppm	344.0	600	0.5	-	-	-
CH_4	1.62 ppmv	1.70	3.3	1	6.5	-	-
N_2O	305 ppbv	310	600	0.25	170	-	-
F11	170 pptv	220	673	5	70	1.0	1.0
F12	290 pptv	390	1325	5	144	0.9	3.4
F22	50 pptv	87	631	11.7	17	0.05	0.35

*Relative to F11.

**Hydrocarbon Global warming potential relative to F11.

***Value for 2050 are on the basis of constant atmospheric emissions on Montreal products after 1985, using 1986 production as the atmospheric flux, for other trace gases using a linear rate of charge and for CFC-22 to grow linearly by an additional 76 gN/year after 1985.

Role of Greenhouse Gases in Global Warming

Most of the human derived CO_2 is generated from the fossil fuels that make important contribution in global warming. Excess of carbon dioxide has already accumulated since the beginning of the planet by 1.3 Watt/m^2, when the other absorbing gases are also considered. According to an estimate, the concentration of CO_2 shall double from 300 to 600 ppm by the year 2030, yielding a net radioactive heating of about 4 Watt/m^2.

Absorption by other gases at different wavelengths has a disproportionate importance in the overall greenhouse effect. Methane is 25 times more effective as the same number of CO_2 molecules, and freons have an effect of 10,000 times greater than

CO_2. The record of direct temperature measurements over the last hundred years shows an increase in mean surface air temperature between 0.3^0C and 0.6^0C. This is too large a change that can lead to other factors such as solar output or volcanic gas emissions. The consensus climate models now predict that global average surface temperature will rise about 1°C in the next 40 years and around 3°C by the year 2100. However, these models currently ignore a number of possible feedback mechanisms. For example, they will decrease rainfall in arid areas and cause about a meter of sea level to rise by 2100.

Human Consequences of Global Warming

i. 5% to 50% increase in drought frequencies.
ii. 15% destruction of the arable land in countries like Egypt and Bangladesh.
iii. Overwhelming of nations like Maldives and Kiribati by rising sea level.
iv. Millions of environmental refugees.

Ecological Consequences of Global Warming

i. A warmer globe would change the latitudinal stratification of plant life due to changes in soil moisture.
ii. Sea level rise due to thermal expansion of water and melting of global ice-sheets.
iii. Non-adaptability of ecosystems as a whole due to sudden changes in the temperature.

However, there are ways through which climate change can be prevented. They include energy efficiency, development of environmentally sound energy sources, increasing the biospheric sinks of carbon through afforestation and other practices.

OZONE DEPLETION

Ozone (O_3) is a triatomic form of oxygen. It is found largely in the stratosphere that extends from about 6 km at the poles and 17 km at the equator to about 50 km above the earth's surface. It is present in traces (less than 1 ppm) in the atmosphere. It has a peak concentration (10 mg kg^{-1}) in the stratosphere. Ozone has been the most reactive form of molecular oxygen and the fourth most powerful oxidizing agent. It has a pleasant concentration at about 2 ppm or less, but higher concentration is irritating. It is used as a disinfectant and bleaching agent.

In nature O_3 is formed in the stratosphere when ultraviolet light strikes an oxygen molecule. A photon splits the oxygen molecule into two highly reactive oxygen atoms (O). These combine quickly with an oxygen molecule to form ozone. The O_3 readily absorbs UV light and dissociates into its constituent components.

$$O_2 \xrightarrow{\text{UV-light}} 2O + 2H^+$$

$$O + O_2 \xrightarrow{\text{UV-light}} O_3$$

Being a natural constituent of the stratosphere, O_3 is regularly formed and destroyed in a cyclic manner with solar radiation as the driving force. In the absence of any other disturbances, O_3 settles into a dynamic steady state in which the rate of its formation is equal to the rate of its destruction.

Ozone works like an umbrella and protects life from the harmful UV radiations coming from cosmic rays to earth. Inspite

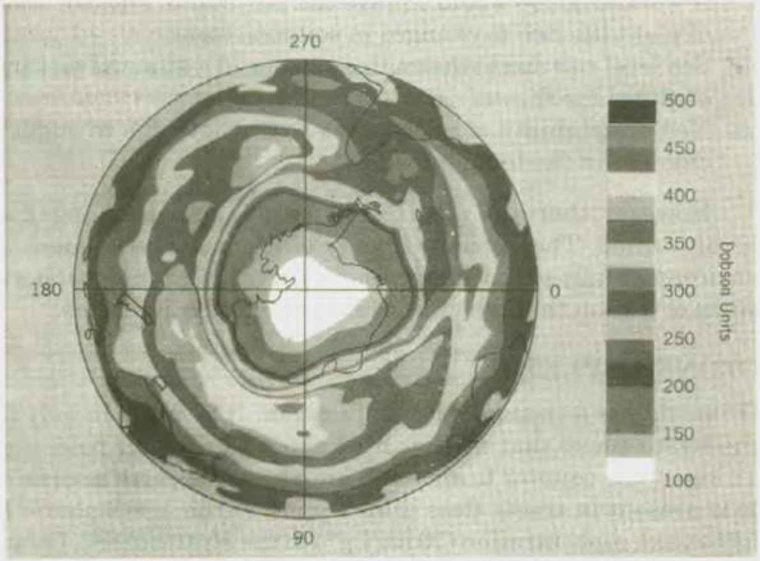


Figure 2.2: Ozone hole in October 1993 (Source: NASA)

of being a trace gas, it plays a major role in the maintenance of climate and biology of earth. It filters out all radiations below 3000 A° (UV-B radiations) that are biologically harmful, and controls the heat budget of the earth.

Processes Causing Ozone Depletion

The ozone story began with Johnston's warning in the seventies of a possible depletion caused by nitric oxides as exhaust from supersonic aircrafts. However, it received little attention till the discovery of **Antarctic Ozone hole** by British scientists from a single Dobson Instrument operating at Halley Bay. Data gathered by US NIMBUS-7 satellite further confirmed their observations. Further examination of balloon measurements made at the Japanese station Swoya showed the "hole" to be primarily at 15 to 20 km. The discovery prompted a number of special campaigns: the National Ozone Expendition I (NOZE-I) in 1986 and NOZE-II in 1987. India participated in 1987 and subsequent campaigns by launching a series of balloons carrying ozone measuring instruments over its base at Antarctica known as **Dakshin Gangotri**. These activities focused attention dramatically on the frail nature of stratosphere and the role of ozone as a screen for biologically hazardous ultraviolet 'B' radiation.

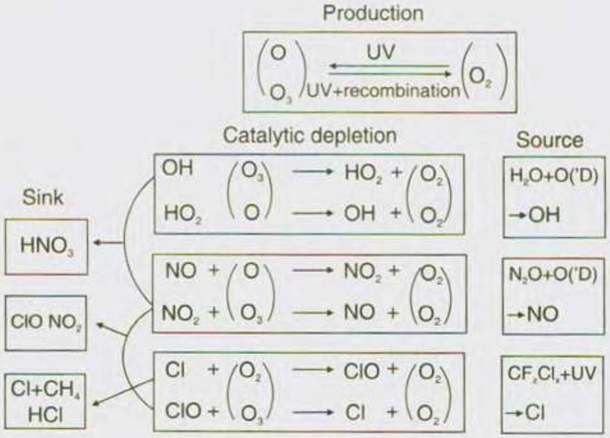


Figure 2.3: Coupling between radical species OH, NO and Cl

Three processes cause ozone depletion. Radiations from the sun create and destroy ozone, but at some what different wavelengths. There are a host of chemical reactions occurring between O, O_2 and O_3 and a number of other molecules that have greenhouse effect. The key is the catalytic action by a number of radical species viz. H, OH, NO, Cl or Br. In a catalytic process, a catalyzing atom or a molecule keeps converting ozone into molecular oxygen again and again without itself being destroyed. The ozone scheme is summarized in Fig. 2.3.

Hydrogen System

The OH system destroys only 10% of O_3, but is dominant above 40 km.

$$H_2O + O(ID) \rightarrow 2OH$$

Reactions particularly important above 40 km.

$$\begin{aligned} OH + O_3 &\rightarrow HO_2 + O_2 \\ HO_2 + O &\rightarrow OH + O_2 \\ \text{net } O + O_3 &\rightarrow 2O_2 \end{aligned}$$

OH can also be formed from oxidation of methane

$$CH4 + O(ID) \rightarrow CH3 + OH$$

H, OH, HO_2 interconvert rapidly by reactions with O, so that all these tend to be in steady state. The scavenging reaction

$$OH + HO_2 \rightarrow H_2O + O_2$$

results in the formation of H_2O which drifts out of strato-sphere. Since this reaction removes odd hydrogen out of the active system, its rate is one of the most important elements in stratospheric chemistry.

Nitrogen System

Sixty percent of ozone destruction occurs through this system. The sequence is as follows:

$$\begin{aligned} N_2O + O(ID) &\rightarrow 2NO \\ NO_2 + h\upsilon &\rightarrow NO + O \end{aligned}$$

and NO so formed catalyses ozone by:

$$\begin{aligned} &NO + O_3 && \rightarrow NO_2 + O_2 \\ &NO2\ O && \rightarrow NO + O_2 \\ &\text{net:}O_3 + O && \rightarrow 2O_2 \end{aligned}$$

The Modern Photochemical Theory

Chapman (1930) explained the existence of a stratospheric ozone layer by a simple photochemical theory, relying on the photodissociation of molecular oxygen by wavelengths shorter than 242 nm. It was found by Craig (1950) that the destruction of ozone was produced by simultaneous action of photochemical and transport processes

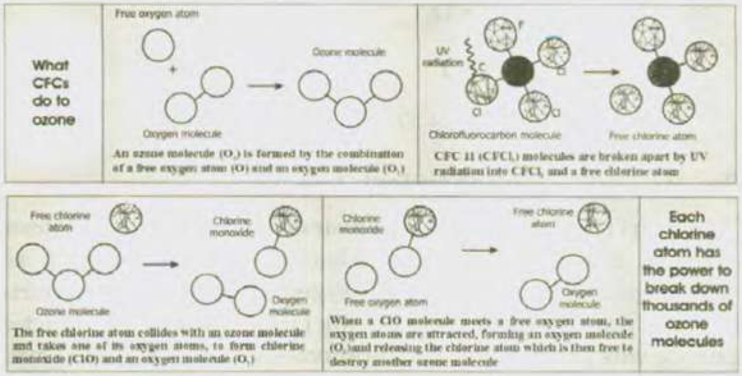
The Simple Chapman Model

$$\begin{aligned} &O_2 + h\upsilon && \rightarrow O + O \leq 242 \text{ nm} \\ &O_2 + O + M && \rightarrow O_3 + M \\ &O_3 + h\upsilon && \rightarrow O_2 + O \leq 1180 \text{ nm} \\ &O_3 + O && \rightarrow 2O_2 \end{aligned}$$

It was successively complemented by ozone destroying catalytic processes mainly produced by the radical groups like HOx, NOx, ClOx. These H_2O, N_2O, chlorofluorocarbons (CFCs), CH_3Cl, CCl_4, and CH_4 are stable molecules which accelerate the reaction (4). The radicals are produced from the source gases by reactions with OH radical or through photodissociation by UV radiation at the same wavelength that yields ozone viz. followed by a rapid decay of the radical CH_2Cl producing a free Cl atom.

$$\begin{aligned} &H_2O + O(ID) && \rightarrow 2OH \\ &CH_3Cl + OH && \rightarrow H_2O + CH_2Cl \\ &CFCl_3 + h\upsilon && \rightarrow CFCl_2 + Cl \end{aligned}$$

Each chlorine atom has the power to break down thousands of ozone molecules as shown in Fig. 2.4.



An ozone molecule (O_3) is formed by the combination of a free oxygen atom (O) and an oxygen molecule (O_2)

CFC 11 ($CFCl_3$) molecules are broken apart by UV radiation into $CFCl_2$ and a free chlorine atom

The free chlorine atom collides with an ozone molecule and takes one of its oxygen atoms, to form chlorine monoxide (ClO) and an oxygen molecule (O_2)

When a ClO molecule meets a free oxygen atom, the oxygen atoms are attracted, forming an oxygen molecule (O_2) and releasing the chlorine atom which is then free to destroy another ozone molecule

Figure 2.4: Breakdown of ozone molecules by CFCs

Dr. Susan Solomon

Dr Solomon was the leading scientist and has been given the prize for 'pioneering work' in identifying the mechanism through which chlorine compounds from CFCs coupled with the extremely low temperatures of Antarctica to create the Antarctic ozone hole. Her finding provided one of the scientific cornerstones of the process that led to the accelerating phase-out of CFCs through the Montreal Protocol.

$$\begin{aligned} O_2 + Cl &\rightarrow O_2 + ClO \\ O + ClO &\rightarrow O_2 + Cl \\ O_3 + O &\rightarrow 2O_2 \end{aligned}$$

The three principle radical species, OH, NO and Cl coming primarily from H_2O, N_2O and $CFCl_3$ respectively and interacting with ozone catalytically eventually end up as sink species HNO_3, $ClONO_2$ and HCl.

Anthropogenic Damage to the Ozone Layer

While most of the source gases are of natural origin, others have been introduced in nature by man. It was thus realized that there is a growing probability of damage to ozone layer by human activities. In early seventies, supersonic transport was the chief cause of NO_x radical output into the stratosphere. After the discovery of CFC problem in mid-seventies, ozone destruction by active chlorine (ClO_x) has become a dominating question. Considering all other changes in trace gas system e.g., N_2O, CH_4 and CO_2, cooling of the stratosphere has been forecasted leading to low loss of total ozone.

It was found that the hole, commonly called "*Antarctic Ozone hole*", was formed each year after the return of the sun at the end of polar night. Development of the phenomenon occurred parallel to the increase of the atmospheric chlorine content produced by the emission of CFCs. The ozone destroying processes in that region influence the whole southern hemisphere.

Since the early seventies, when CFCs came into market, a large quantity has been injected into the atmosphere. The present level of injection is about 7, 00,000 tonnes/year for CFC-H ($CFCl_3$) and CFC-12 (CF_2Cl_2) taken together. Production of CFCs in India is around 5000 tonnes/year. CFCs released upto 1987 amount to 15 million tonnes. The developed countries account for 1.2 kg per annum *per capita* of CFCs as against less than 0.006 kg per annum of the developing countries. Global consumption of CFCs estimated in 1995 accounts to 1.2 million tonnes per year. CFCs released upto 1987 amounted to 15 million tonnes. Since the life of these molecules is around 100 years, even with the adoption of protocols put forward at Montreal and London, which were further refined at Copenhagen and Kyoto to make them acceptable to all countries, the ozone layer is not likely to make a significant recovery until the middle of century. For the ozone layer to return to its natural state, the chlorine loading, which is presently 3 ppbv, has to be brought down to a level below 2 ppbv.

Health Effects of Ozone Depletion and Increased UV-B Radiation

An increase in the CFC levels in the stratosphere has decreased the ozone levels but increased the UV-B radiation (290-320 nm) reaching the earth's surface. Though overall consequences of UV-B radiation on human health cannot be predicted in a straight forward manner, increased incidences of diseases like skin cancer, cataracts, suppression of the immune system, which may affect the herpes viruses, leishmaniasis, malaria, bacterial and fungal infections, tuberculosis and respiratory problems have been recorded. A few examples are discussed below.

Ocular Effects

The World Health Organization estimates that cataracts were responsible for 17 million cases of avoidable blindness in 1985. By reducing 1% of the ozone level, there would be 1,00,000 to 1,50,000 additional cases of cataract induced blindness.

Skin Cancer

Increased UV-B levels are expected to cause an increase in cancer related skin disorders, including melanoma skin cancer (MSC), non-melanoma skin cancer (NMSC) and pre-cancerous lesions. The number of patients will increase more sharply than the rate of decrease in ozone layer.

Immunological Effects

Ultraviolet radiation has profound effects on the immune system, particularly that of the skin. All diseases that affect skin at a stage like measles, malaria, leishmaniasis, tuberculosis and leprosy are known to be effected by UV-B induced immune-suppression.

Respiratory Problems

Respiratory problems are caused by a variety of air pollutants. These problems are magnified with ozone depletion. Ozone depletion in stratosphere will result in increased levels of ozone in troposphere. The individuals who are sensitive to ozone and are exposed to air pollution will also face serious respiratory problems i.e., bronchitis, asthma etc. According to an estimate, about 50,000 cases of lung diseases caused by ozone were reported in Bombay alone.

Animal Health

UV-B radiation causes squamous cell cancer of the eye of cattle. Most animals, because of their heavy coats, are not likely to suffer from the immunosuppressive effects of UV radiation, but global warming may change the patterns of animal disease via changes in the prevalence and distribution of insect vectors.

Crop Yield

Increase in ozone concentration influences crop yields. It enters the levels through stomata and reduces the yield and quality of the plant products. It was reported that ozone depletion caused 50% crop losses in several European countries, mainly effecting potato, spinach, clover, alfa alfa, beans, poplar etc.

EL-NINO

El Nino is the term that was applied by Peruvian fishermen to a period of reduced fish-catch due to rise in sea surface temperature off the coast of Ecuador and Peru. It typically occurred around the Christmas, therefore, it was called "**Christ Child**". In 1966, Jacob Bjerknes of University of California at Los Angeles demonstrated a relationship between El Nino and weather extremes. In 1982 and 1983, El Nino made new headlines and was blamed for weather extremes in many parts of the world. Heavy rains and flooding in these years plagued normally dry portions of Ecuador and Peru. Some locations that normally receive 10 to 13 centimetres of rain had as much as 3.5 metres of precipitation. At the same time severe drought beset Australia, Indonesia and Phillipines. Huge crop losses, property damage and much human suffering were recorded. Farther-north, one of the warmest winters on record was followed by one of the wettest springs for much of the United States. The ferocious storms that struck the California coast brought un-precedented beach erosion, land slides and floods. Excessive rains brought floods to the Gulf States and Cuba.

Figure 2.5: *A satellite image of the Pacific Ocean taken on June 25 1997 shows that the weather disrupting phenomenon known as El Nino is getting stronger. The white and red areas (where El Nino emerges) indicate the abnormal warming up of the ocean. This area is about one and a half times the size of the US. The green areas indicate normal conditions.*

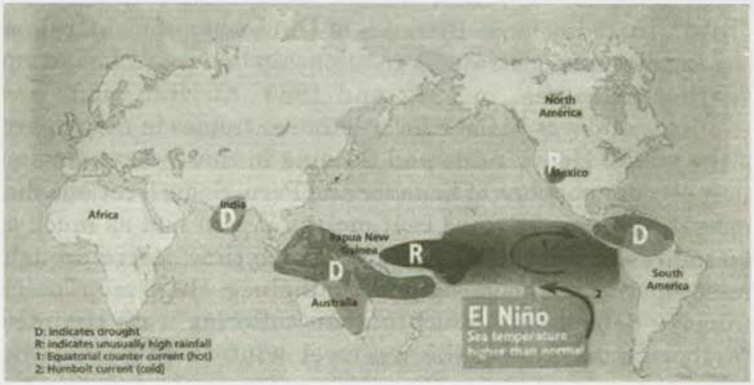


Figure 2.6: *Association of El Nino with drought in Indonesia, Northern Australia, India and Northeastern Latin America and with heavy rainfall in parts of North America.*

ENSO

Major El Nino events are intimately related to large scale changes of atmospheric circulation in the Pacific. These circulation anamolies involve both the tropical atmosphere and ocean. Each time the El Nino occurs, the barometric pressure over large portions of the south-eastern pacific drops, whereas across the pacific, near Indonesia and northern Australia, the pressure rises. Moreover, when the El Nino event ends, the pressure difference between these two regions swings back in the opposite direction. This sea saw pattern of atmosphere between the eastern and western Pacific is known as *Southern Oscillation*. Collectively, it is called El Nino Southern Oscillation **(ENSO)**. It is an inseparable part of the warming that occurs in the central and eastern pacific every 3 to 10 years.

Typically, pacific trade winds converge near the equator and move westward into a semipermanent region of low pressure near Indonesia. This steady westward flow of air drags the warm surface waters to the west. The result is the "piling up" of a thick layer of warm surface water and a higher sea-level in the western pacific. Meanwhile, strong coastal **upwelling** of cold water and a lower sea-level characterize the eastern pacific. The phenomenon of southern oscillation that occurs due to unknown reasons changes the normal situation dramatically. Barometric pressure rises in the Indonesian region, causing sthe pressure gradient along the equator to weaken. Consequently, easterly winds in the western pacific diminish and then change the direction. This reversal creates a major change in the equatorial current system, with warm water moving towards the east. With time, water temperatures in the Eastern pacific increase and the sea-level rises in the region. These events lead to the development of El Nino.

La-Nina

Recently, a phenomenon opposite to El Nino has been reported by scientists. Literally, La Nina means "the girl". La Nina features strong trade winds and unusually low sea-surface temperatures in the central and eastern tropical Pacific. An intense La Nina may also be linked to weather extremes in mid-latitudes. For example, the US drought in 1988 coincided with an intense La Nina.

Impacts of El Nino

It is difficult to be precise about the impacts of El Nino, although enough historical data in the last 50 years has been gathered to make some intelligent guesses. Direct impacts of El Nino range from storms in the western United States, and the disappearance of fish along the Peruvian coast. Storms occur due to warming of the air, which rises due to convection causing unsettled weather. Fish stocks decline because a rise in sea surface temperatures disturbs the phenomenon of upwelling, thus changing the ecological conditions in the coastal waters. Peruvian and Chilean coasts are located in the zone of *upwelling*. This means that under normal conditions nutrients dissolved in deep waters are continuously brought to the surface. During El Nino, the cycle of upwelling is disturbed causing delicate ecological imbalances.

In 1982-83, El Nino directly affected fish stalks not only in South America but also in the US. The indirect effects of El Nino are many. A severe storm can result in loss of life, destruction of infrastructure and disturbances in regional economics, which in turn can affect international economy.

El Nino and its Effects on Climate

The El Nino event of 1997, first noticed in January, has caused a sensation. Those who love drama have dubbed it as the climate event of the century. That may be an exaggeration, may be not, only time will tell. Previous El Nino episodes, for instance in 1982-83, took scientists by surprise. But the El Nino occurrence this year has certainly focused attention on the relationship between man, natural elements and the place of science in predicting and mitigating the adverse effects of natural disaster.

BIODIVERSITY

Biodiversity can be defined as species richness (plants, animals and microorganisms) occurring as an interacting system in a given habitat. It is the total sum of genes, species and ecosystems. Thus, biodiversity conservation encompasses the whole spectrum of biota and their activities ranging from the macrolevel of ecosystems to the microlevel of DNA libraries.

Biodiversity exists on the earth in eight broad realms with 193 biogeographical provinces. Each biogeographical province is composed of ecosystems, which are constituted by communities of living species existing in an ecological region. It can be generally described in terms of its three fundamental and hierarchically related levels of biological organizations. These are:

- Ecosystems or ecosystem diversity
- Species or species diversity
- Genes or genetic diversity

There are two main functions of biodiversity. Firstly, on it depends the biosphere, which in turn leads to the stability in climate, water, soil, chemistry of air, and the overall health of biosphere. Secondly, biodiversity is the source of species on which the human race depends for food, fodder, fuel, fibre, shelter, and medicine. By and large, biodiversity exists in the 12 Vavilovian Centres of Diversity (Vavilov, 1951). Biodiversity is not only an important resource but also a strength of the developing countries. Since biodiversity is an irreplaceable resource, and its extinction is forever, the conservation and sustainable utilization of this resource has to be central to all developmental planning in the developing countries. Economy of these countries is largely dependent on agriculture, horticulture, animal husbandry, fisheries, forestry, and medicinals, and biodiversity has been kept alive by farmers, tribals and individual breeders. The genes from wild ancestors of crops, endemic to the developing countries, have made significant contribution in crop improvement, which in turn has resulted into social and economic development.

Biodiversity—Hot Spots

Hot spots are the areas that are severely threatened by human activities. At the same time they contain outstanding examples of evolutionary processes of speciation and extinction. All those areas that support rich biodiversity, because of geologic formations and endemic flora and fauna, and exhibit exceptional scientific interest are called hot spots.

Mittermeir and Werner (1990), using the criteria of species richness, introduced the concept of Megadiversity centres. Following their concept, 12 countries/regions namely Mexico, Columbia, Ecuador, Peru, Brazil, Zaire, Madagascar, China, India, Malaysia, Indonesia and Australia have been classified as Megabiodiversity centres. At the global level, Myers (1988) has identified 10 hot spots of tropical forests to which he later added 8 areas. These areas collectively include 49,955 endemic species, which constitute 20 per cent of the world's total plant species. Two regions from India, namely, the Eastern Himalaya and the Western Ghats are included as hot spots.

Table 2.2: *The global hot spots and the number of endemic species*

Region	Number of plants
Cape Region (South Africa)	6,000
Upland Western Amazonia	5,000
Madagascar	4,900
Philippines	3,700
Borneo (North)	3,500
Eastern Himalaya (India)	3,500
SW Australia	2,830
Western Ecuador	2,500
Colombian Choco	2,500
Peninsular Malaysia	2,400
Californian Floristic Province	2,140
Western Ghats (India)	1,600
Central Chile	1,450
New Caledonia	535
Eastern Arc Mts (Tanzania)	535
SW Sri Lanka	500
SW Coted Tvorie	200
Total	**49,995**

Broadly, the botanical hot spots lie in the (i) Western Ghats, (ii) North-east India, (iii) Himalayas and (iv) Andaman and Nicobar Islands.

The Western Ghats, particularly the southern Western Ghats, known as Malabar is the major genetic estate with an enormous biodiversity of ancient lineage. Out of five locations identified by IUCN as threatened, three areas, Periyar Agastyamalai Hills, Silent valley and Periyar National Park are found in this region.

Northest India represents the transition zone between the Indian, Indo-Malayan, Indo-Chinese biogeographic regions as well as meeting place of Himalayan Mountains with that of peninsular India. Some of the hot spots in this zone are

Namdapha, Tirap, Sirohi, Dzuko, Tura, Buxa valley, Senchal and Tale valley.

Western Himalaya is quite remarkable for its alpine flora. Gymnosperms are quite abundant. About 5000 flowering plants occur here of which 800 species are endemic. Some major hot spots of this region are Valley of Flowers, Pithoragarh, Gori valley, Mandal-Chopta valley, Karakorum and Ladakh.

The Andaman and Nicobar islands have a rich flora under littoral and island types. About 2500 species of flowering plants are found here of which 250 species are endemic. Some of the hot spots of this region are North Andaman, Table islands, South reef island, Spike island and little and Great Nicobars.

Sacred forests: These are the real hot spots of biodiversity. They are protected by tribals due to some religious sanctity attached to them. These sacred forests contain a number of rare, endangered, endemic or interesting biota of the country. They are known as 'Devaskadu' in Karnataka, 'Devarahati' in Maharashtra, and 'La-Kyntok' in Meghalaya.

Mangroves: Mangroves are the salt tolerant forest ecosystems found mainly in the tropical and subtropical inter-tidal regions. The total area of mangroves in India is estimated to be 6740 km^2, of which the mangroves of Sunderbans itself contribute 4200 km^2, next being the Andaman and Nicobar islands. The quality and quantity of mangroves in India have greatly declined. The following mangrove areas must be considered as hot spots for conservation purposes:

Andaman: North Andaman, Prolobjig, Bomlungta, Havelock island and Wrafter creek (South Andaman).

Nicobar: Komorta, Noncowry islands, Bolloo Chengappa Bay and a few sheltered bays on Great Nicobar islands.

East coast: Sunderbans; Bhitarkanika; Mangroves and Godavari and Krishna Deltaic mangroves, Coringa Bay.

West coast: The Gulf of Kutch and Gulf of Kahambt, Vembanad in Kerala.

GLOBAL BIO-WEALTH

Biodiversity is not distributed uniformly across the globe. It is substantially greater in some areas than the others. Generally, species diversity increases from the poles towards the tropics. Tropical moist forests cover only 5–7 per cent of the land, but possess 50 per cent of the world species. On the other hand, though certain regions may not have a high diversity, but they display a high degree of endemism. However, a less diverse system does not mean that the region is not important.

Table 2.3: *Known and estimated diversity of life on earth*

Form of life	Known species	Estimated total species
Insects and other arthropods	874,161	30 million species, extrapolated from surveys in forest canopy in Panama; most believed unique to tropical forests
Higher plants	248,400	Estimates range from 275,000 to 400,000; at least 10–15 per cent species believed undiscovered
Invertebrates (excludes arthropods)	116,873	True invertebrates may number millions of species. Nematodes, eelworms, and roundworms may eachcomprise more than one million species.
Lower plants (fungi and algae)	73,900	Not available
Microorganisms	36,600	Not available
Fish	19,056	21,000, assuming that 10 per cent fish remain undiscovered; the Amazon and Orinoco rivers alone may account for 2,000 additional species.
Birds	9,040	Known species probably account for 98 per cent of all birds.
Reptiles and Amphibians	8,962	Known species probably account for over 95 per cent of all reptiles and amphibians.
Mammals	4,000	Known species account for over 95 per cent of all mammals.
Total	1,390,992	10 million species is considered a conservative estimate. If insect estimates are accurate, total exceeds 30 million.

Source: E.C. Wolf (1987). On the brink of extinction: Conserving the Diversity of Life. Worldwatch Paper 78.

Bio-Wealth of India

Biodiversity is indeed one of India's important strengths and is the bedrock of all bio-industrial developments in the unusually large rural sector (576,000 villages with 76 per cent of country's population) of the country.

India has over 108,276 species of bacteria, fungi, plants and animals, already identified and described (Table 2.4). Out of these, 84 per cent species constitute fungi (21.2 per cent), flowering plants (13.9 per cent) and insecta (49.3 per cent). In terms of the number of species, the insecta alone constitute nearly half of the biodiversity in India (Figure 2.6).

These species occur on land, fresh and marine waters, or as symbionts in mutualistic or parasitic state with other organisms. In the world as a whole, 16,04,000 species of Monera, Protista, Fungi, Plantae and Animalia have been described so far. However, it is estimated that at least 179,80,000 species exist in the world, but as a working figure 122,50,000 species are considered to be near reality (WCMC, 1993).

Table 2.4: *Number of species of bacteria, fungi, plants and animals in India*

Taxon	Number of species	Percentage
Bacteria	850	0.8
Fungi	23,000	21.2
Algae	2,500	2.3
Bryophyta	2,564	2.4
Pteridophyta	1,022	0.9
Gymnosperms	64	0.1
Angiosperms	15,000	13.9
Insecta	53,430	49.3
Mollusca	5,050	4.7
Pisces	2,546	2.4
Amphibia	204	0.2
Reptilia	446	0.4
Aves	1,228	1.1
Mammalia	372	0.3
Total	**108,276**	**100.00**

Based on this data and the already described species, India is 10th among the plant rich countries of the world, fourth among the Asian countries, eleventh according to the number of endemic species of higher vertebrates (amphibia, birds and mammals), and tenth in the world as far as richness in mammals is concerned. Out of the 18 'Hot spots' identified in the world, India has four. These are Eastern Himalaya, North-east India, Western Ghats and Andaman and Nicobar Islands. The two areas—Eastern Himalayas and Western Ghats—contain 5,332 endemic species of higher plants, mammals, reptiles, amphibia

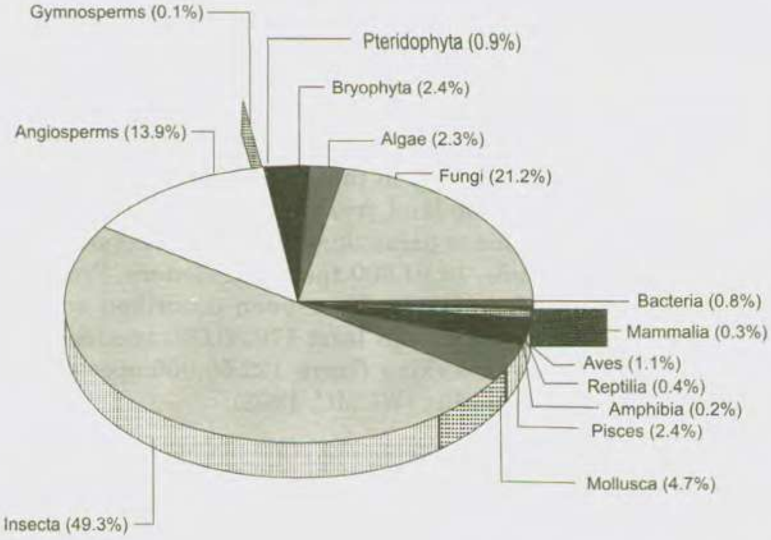


Figure 2.7: *Diagram showing percentage of different biota in India*
Source: BSI and ZSI, 1994 (also Khoshoo, 1990)

and butterflies (WCMC, 1993), to name a few. The crops that first grew in India and spread throughout the world include rice, sugarcane, Asiatic vignas, jute, mango, citrus, banana, several species of millets, spices, medicinals, aromatics, and ornamentals. India ranks sixth among the centres of diversity and origin as far as agro-biodiversity is concerned (Khoshoo, 1990).

Loss of Biodiversity

Species are now dying out as fast as it did since the mass extinction at the end of createaceous period, some 65 million years ago (Reid et al. 1992). Tropical deforestation is the cause of today's extinction crisis. About 17 million hectares of tropical forests are cleared every year. If this trend continues, at least 5–10 per cent of tropical forest species will face extinction in the next 30 years (Fig. 2.7).

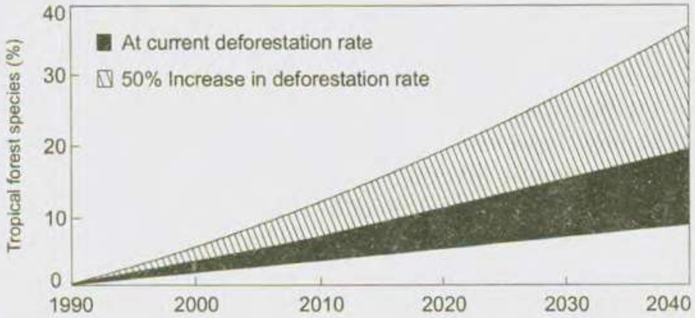


Figure 2.8: *Percentage of tropical forest species likely to become extinct*

The list of species at risk is swelling. Some 633 species are listed as being in danger of extinction in the United States alone, and more than 3,000 other species have been proposed for listing. In the past several hundred years, 80 species are believed to have become extinct in the continental United States and Hawaii, and a further 210 species are likely to be extinct. One-third of North America's fresh water fish are rare, threatened or endangered. Worldwide, more than 700 extinctions of vertebrates, invertebrates and vascular plants have been recorded since 1600 (Reid et al., 1989). In Indonesia, 1500 local rice varieties have become extinct in the past 15 years. Worldwide, some 492 genetically distinct populations of tree species are endangered. In north-western United States, 169 genetically distinct populations of anadromous fish are facing the risk of extinction.

Though biological extinction has been a natural phenomenon in geological history, the rate of extinction was perhaps one species per 1,000 years. However, between 1600 and 1950, the rate increased to one every ten years and currently it may be one every year. According to an estimate of Forest Survey of India, only 640,164 sq. km. of forest is left now out of a 4,017,009 km. Faunal losses have been mainly due to overexploitation, habitat alteration and pollution. The other possible reasons for the loss of species could be improper use of agrochemicals and pesticides, a rapidly growing human population, inequitable land distribution and economic and political policies and constraints.

However, extinction is not caused by a single reason but by the cumulative effect of a host of causes. The earth's biodiversity being one big interlink, the loss of one species in most cases triggers off the downward slide and consequent loss of many other dependent species.

Decline in genetic diversity in agriculture is costly as well. The Irish potato famine in 1846, the Soviet wheat crop loss in 1972, citrus canker in Brazil in 1991, all have been the result of loss of genetic diversity.

We pay high cost for the loss of a species. The water we drink, the air we breathe, our fertile soils, and our productive seas are all products of healthy biological systems. The loss of ecosystems, for instance, wetlands that provide critical services such as flood control, fish production, and pollutant assimilation is a direct economic cost as well as threat to species survival. Loss of biodiversity also destroys opportunities of recreation and tourism business—now worth as much as $12 billion a year worldwide.

Biodiversity Conservation

Undoubtedly, the need to save biodiversity is of utmost urgency. We all wish to retain our life supporting system. The maintenance of species and ecosystems is a keystone to sustainable development—a development that meets the needs of present generation without compromising on the ability of the future generations to meet their needs.

As already discussed in the preceding chapter, biodiversity can be conserved in two ways, e.g., *ex-situ conservation* and *in-situ conservation*. A decade ago, biodiversity conservation was limited to saving genes, species and habitats. But now a new conservation framework has emerged based on saving biodiversity, studying it and using it sustainably.

The steps needed go far beyond maintaining protected areas and seed banks to include reforming agricultural forestry and technological policies and revamping international trade agreements and watershed management. Within this framework, countries, be they developed or developing, as well as scientists, non government organizations and the private sector can see the relevance of biodiversity to their needs. Different activities can therefore be linked to biodiversity conservation and use. The scope of biodiversity conservation links resources, development, trade, economics and human rights etc.

Levels of Action

Biodiversity conservation is gaining ground precisely because the issue is so vast that it can encompass the interest of so many countries. Four major steps have been taken to shape an international response to the loss of biodiversity to support the actions already underway at local, regional and national levels.

(i) ***Global Environment Facility (GEF).*** World Bank, United Nations Development Programme, United Nations Environment Programme established the Global Environment Facility in 1991 on a three-year pilot basis. The GEF is expected to commit $400 million to conserve biodiversity.

(ii) ***International Biodiversity Strategy Programme.*** World Resources Institute, World Conservation Union, UNEP and more than 40 governmental and non-governmental organizations outlined the programmes to stop the loss of biodiversity and mobilize its benefits to human needs sustainably and equitably.

(iii) ***Convention on Biological Diversity.*** Under the auspices of UNEP, more than 100 nations met during Earth Summit at Brazil (1992) to establish a legal framework governing international financial support for biodiversity conservation, the identification of international conservation priorities and technology transfer for conservation and use of biodiversity.

(iv) ***Agenda* 21.** Developed through a series of intergovernmental preparatory meetings—with input from a variety of non-governmental processes including the Biodiversity Strategy Programme—AGENDA 21 provides a plan of action on a number of issues including biodiversity.

Promising moves are under way to slow down the loss of biodiversity and mobilize its benefits for human well-being.

Many of today's positive initiatives may turn out to be stop-gap arrangements unless advances are made in dealing with overconsumption of resources, population growth, misguided resource management policies and social and economic inequities. The need to conserve our planet's biological wealth gives nations even more impetus to solve these knotty problems. At the same time, sustaining bio-diversity may help provide the means for crafting solutions.

SOLID WASTE POLLUTION

Solid waste, often called the third pollution after air and water pollution, is that material which arises from various human activities and which is normally discarded as useless or unwanted. It consists of the highly heterogeneous mass of discarded materials from the urban community as well as the more homogeneous accumulation of agricultural, industrial and mining wastes.

Solid wastes may be classified based partly on content and partly on moisture and heating value. A typical classification is as follows:

(a) ***Garbage*** refers to the putrescible solid waste constituents produced during the preparation or storage of meat, vegetables, etc. These wastes have a moisture content of about 70 per cent and a heating value of around 6×10^6 J/kg.

(b) ***Rubbish*** is the non-putrescible solid waste constituents, either combustible or non-combustible. Combustible wastes include paper, wood, scrap, rubber, leather, etc. Non-combustible wastes are metals, glass and ceramics. These wastes contain a moisture content of about 25 per cent and the heating value of the waste is around 15×10^6 J/kg.

(c) ***Pathological wastes*** include dead animals and human waste. The moisture content is 85 per cent and there are 5 per cent non-combustible solids. The heating value is around 2.5×10^6 J/kg.

(d) ***Industrial wastes*** generally include chemicals, paints, sand, metal ore processing, flyash, sewage treatment sludge, etc.

(e) ***Agriculture wastes*** contain mainly farm animal manure and crop residues.

The principal sources of solid wastes are domestic, commercial, industrial and agricultural activities. Many times domestic and commercial wastes are considered together as the so-called urban wastes. The main constituents of urban wastes are similar throughout the world, but the weight generated, the density and the proportion of constituents vary widely from country to country, and from town to town within a country according to the level of economic development, geographic location, weather and social conditions. In general, it has been found that as the personal income rises, kitchen wastes decline, but the paper, metals and glass wastes increase. While the total weight generated rises, the density of the wastes declines.

In India, authentic information regarding the composition of the urban wastes is not generally available, as regular analysis of the refuse is not carried out by the municipalities. In fact, refuse is very heterogeneous in composition and the geographical, temporal and seasonal variations in its composition make it difficult to define a 'typical refuse'. The solid refuse generated in urban areas contains articles of various sizes and types and consists of dust, vegetable levels, waste paper, large paper-board cartons, glass bottles, worn out tyres, carcasses of animals and night soil. Table 2.5 gives the composition of refuse in various cities of India, and a comparison is made with the urban refuse from a typical European city. As seen in this table, the average paper content in the refuse of Indian cities is about 2 to 3 per cent as compared with about 27 per cent for a typical European city. Similarly, the density of refuse in India is much higher than that of the refuse generated in the cities of Western countries because of the inclusion in it of the street sweepings. The amount of refuse collected from urban areas in India is of the order of 0.3 kg to 0.5 kg per person per day excluding night soil.

Table 2.5: *Composition of city refuse (percentage by weight)*

	Kanpur	**Delhi**	**Kolkata**	**Bangalore**	**Bombay**	**Typical European city**
Paper	1.35	5.88	0.14	1.5	3.20	27
Vegetable-putrescible matter	53.34	57.71	47.25	75.2	59.37	30
Dust, ash, etc.	25.93	22.95	33.58	12.0	15.90	16
Metals	0.18	0.59	0.66	0.1	0.13	7
Glass	0.38	0.31	0.24	0.2	0.52	11
Textiles	1.57	3.56	0.28	3.1	3.26	3
Plastics, leather, rubber	0.66	1.46	1.54	0.9	–	3
Other (stones, wooden matter, etc.)	18.59	6.4	16.98	18.9	16.4	3
Density, kg/m^3	500	–	578	–	–	132

Manufacturing industries produce wastes which are solid or semi-solid. These wastes can be pyrophoric (self-igniting), explosive, toxic or radioactive. Chemical process industries (CPI) generate a variety of wastes, both organic and inorganic, which are mixture with a wide range of component concentrations. Table 2.6 gives some of the physical and chemical characteristics of the wastes generated by the CPI.

Table 2.6: *Solid wastes generated in the CPI*

Origin **Comments**	**Physical and chemical characteristics**	
Coke manufacture	Coke and coal fires contained wastes	Generally in scrubber
Dyes and pigments	Reaction raw-material sludge, highly variable	
Pharmaceuticals and Fine-chemicals	Raw material solids, biological wastes	–
Inorganic chemicals	Insoluble salts, tailings, slimes	–
Metal processing (secondary)	Ash, scrubber wastes, metal hydroxide sludges	–
Petrochemicals	Oily, greasy, asphaltic float	Usually
Plastics and rubber	Latex or plastic crumbs, often coagulated	–
Pulp and paper	Fibrous, often mixed with lime or alum	–

Most of the industrial wastes generated in cities come from small scale operations and these are usually disposed off along with the city refuse. Larger industries are often located outside the cities and the disposal of their wastes is primarily the responsibility of the industries themselves. Some of the industrial wastes are often recycled (scrap metal and paper), while others can be utilized as an energy source for specific processing plants in some regions. Energy can be recovered from solid wastes by numerous thermal routes as well as by biochemical conversion. The toxic and radioactive wastes, often classified as hazardous wastes, need special consideration before their disposal.

Agricultural wastes comprise both crop residues and animal wastes such as manure and urine, whereas urban wastes amount to 0.3–0.5 kg per person per day. In India, agricultural wastes amount to around 2 kg per person per day. Animal and vegetable wastes contain valuable minerals and nutrients. Humus from agricultural wastes contains nitrogen, phosphorus, potash and trace elements, which are vital to the fertility of the soil and optimum plant growth. Burning of wastes as fuel further leads to loss of valuable nutrients.

Solid Waste Management

Efficient collection and transportation are essential parts of the overall solid waste management programme, since these two activities constitute about 75% of the total cost. The basic mode of refuse collection in India is from communal storage points. The refuse is delivered to fixed storage bins usually built from concrete blocks, having capacities between 100 and 500 litres and placed at intervals of 50 to 200 metres. The refuse is stored in the bins. It is collected for disposal by a vehicle. Daily collection is essential because the organic matter in the refuse tends to decompose rapidly in the hot climate. The refuse is usually removed using a shovel and a basket from the bin and dumped into the waiting vehicle by the workers. The clearing of the bin is a slow process and the vehicle waiting time is excessive.

Other methods of refuse collection like block collection and kerbside collection are practiced in developed countries. In block collection the waste is brought in containers by individuals to a waiting vehicle, which travels regular route thrice a week. The containers are emptied by the vehicle crew and returned to the individual. In kerbside collection, the waste is brought in containers and placed on the footway in advance of the collection time to be retrieved later.

Transfer Station

A transfer station can be described simply as a place for receiving refuse from a number of small collection vehicles such as hand carts and transferring it to larger line-haul type vehicles capable of undertaking a longer journey more economically. The best construction for a transfer station is a ramp leading to a concrete platform where the smaller vehicles discharge. The refuse is unloaded either by the force of gravity or manually into the transfer vehicles, which wait on a roadway about 5 metres below.

Disposal Methods

Several disposal methods are being used in the various parts of the world and the most prominent of these are open dumping, sanitary land filling (controlled tipping), incineration and composting. Sanitary land filling is the main method used in the developed countries and open dumping is very common in India.

Open Dumping

Open dumping of solid wastes is practiced extensively in India because it is cheap and requires no planning. Generally, the low-lying areas and outskirts of the towns and cities are used for the purpose. The open dumps cause public health problems by encouraging the breeding of flies, rats, mosquitoes and other pests. They also become a source of objectionable odours and cause air pollution when the wastes are burned in order to reduce their volume and conserve space.

Sanitary Landfill

Sanitary land filling is an engineered operation designed and operated according to acceptable standards. It may be defined as a method of disposing refuse on land without creating nuisances or hazards to public health or safety. The operation is carried out without environmental damage and in areas already spoiled or in need of restoration.

In sanitary landfill operation, refuse is spread and compacted in thin layers within a mall area. This layered structure is usually referred to as a cell. To allow for proper compaction, the cell depth should not exceed about 2 metres. The cell is then covered by a layer of soil which is spread uniformly and then compacted. To provide an adequate seal the 'cover' should normally be at least 20 cm thick. If the refuse includes large irregular objects, it may be necessary to increase the thickness of the cover. On the other hand, a cover thickness of less than 15 cm may be satisfactory if the refuse has been pulverized. When a number of cells reach the final desired elevation, a final cover of about one metre of earth is placed and compacted again. This final cover is necessary to prevent rodents from burrowing into the refuse.

The landfill operation is essentially a biological method of waste treatment. The refuse stabilization may be divided into five distinct phases within the overall process. During the first phase of operation, aerobic bacteria, which are dominant, deplete the available oxygen and as a result of aerobic respiration the temperature increases. In the second phase, anaerobic conditions become established and hydrogen and carbon dioxide are evolved through acidogenic activity. Phase three is characterized by the-establishment of methanogenic population of bacteria and the beginning of methanogenic activity. In phase four, the methanogenic activity becomes stabilized. In phase five, the methanogenic activity decreases representing depletion of the organic matter, and ultimately the system returns to aerobic conditions within the landfill. The duration of each phase of land fill activity and degree of degradation varies with prevailing environmental conditions and the nature of the refuse.

Incineration

Incineration involves the burning of solid wastes at high temperatures; leftover ashes, glass, metals and unburned combustibles amount to perhaps 25% of the original waste. This residue must still be disposed of in some manner. Incineration leads to air pollution unless the plant is designed, equipped and operated to comply with air pollution standards. Typical air pollutants from incineration are flyash, SO_2, hydrogen chloride, and organic acids. New techniques of handling the waste have been developed. Thus, materials which are not combustible are removed from the waste by gravity or magnetic separation. Many of the separated materials like glass or metals can be recycled. Air pollution can be controlled by installation of proper control equipment.

Industrial solid wastes that are incinerated are mostly cellulose type, and more often industries have to handle certain kinds of chemical wastes in the form of either solids or sledges. In the chemical process industries, incineration is most frequently used to dispose of tarry and gummy petroleum and plastic intermediate wastes and general refuse. The waste combustibility is an important factor in determining the applicable incineration process. Waste combustibility is characterized by flammability limits, flash point, and ignition temperature. The incinerator chosen must be capable of handling all types of wastes generated in the industrial facility. Multiple hearth, rotary and fluidized bed type incinerators are finding wide applications in industrial waste disposal.

The advantage of incineration includes a wide range ability for handling varying loads and small space requirement for ultimate disposal. However, the method requires fairly high level of maintenance and the operating costs are higher than those for the operation of a sanitary landfill.

Compositing of Solid Waste by Bacteria

In contrast to a sanitary landfill, compositing of refuse is an aerobic method of decomposing solid waste. Many types of microorganisms already present in the waste stabilize the organic matter in the waste to produce a soil conditioner. The organisms include bacteria, which predominate at stages; fungi, which often appear after the first week; and actinomycetes, which assist during the final stages.

Initially, the process starts with the mesophilic bacteria, which oxidize the organic matter in the refuse to carbon dioxide and liberate heat. The temperature rises to about 45°C and at this point the thermophilic bacteria take over and continue the decomposition. During this phase, the temperature further rises to about 60°C. The refuse is periodically turned over to allow sufficient oxygen to penetrate to all parts of the material to support aerobic life. After about three weeks, the compost is stabilized. The end point of a compositing operation can be measured by noting a drop in temperature. The compound should have an earthy smell and a dark brown colour. A moisture content of about' 55% should be established so that biological activity may proceed at an optimum rate. It may be necessary to add water to maintain satisfactory moisture content.

Utilization, Recovery and Recycling of Solid Waste

Many solid wastes generated by industry can be utilized directly. Fly and bottom ash from power plants can be used commercially largely as cement substitute. New uses are being developed for fly ash, e.g., to make bricks, to dewater industrial wastewater sludge, as a land cover etc. India produces about 6×10^6 tonnes of bagasse from sugar cane annually. This bagasse can be utilized for the manufacture of paper pulp, which can displace hardwood pulp of similar quality Ind. cost. There some novel uses of sugar cane bagasse. One sugar cane company in South Africa has integrated its operation with the production of eggs and dairy products.

Solid wastes contain significant amounts of valuable materials like steel, chromium, copper and other metals which, if they are recovered and reused, would reduce the volume of the wastes to be collected and at the same time would yield significant salvage and resale income. In addition, better reclamation techniques will help to save valuable natural resources and turn wastes, which could be dangerous, into useful products. Some important solid wastes that have been successfully reclaimed are paper, glass, metals and plastics.

Public Health Aspects of Solid Waste

The relationship between solid wastes and human disease is difficult to prove. Nevertheless, improper handling of solid wastes is a health hazard and causes damage to the environment. The main risks to human health arise from the breeding of disease vectors, primarily flies and rats. A common transmission route of bacillary dysentery, amoebic dysentery and diarrhoeal disease in India is human faeces carried over by flies to food or water and thence to humans. It has been estimated that in warm climates, exposed garbage produces as many as 70,000 flies per 3 m^2 in a week.

The refuse dumps also serve as a source of food for rats and small rodents, which quickly proliferate and spread to neighboring areas. Rats destroy property, infect us by direct bite and spread various diseases like plague, endemic typhus, salmonellosis, and trichinosis. Apart from diseases for which insects and rats are carriers, the handling and transfer of biological wastes pose a threat to the worker as well as those he contacts. Disease transmission may occur through direct contact with the waste, through infection of open sores or through vectors.

The hazardous wastes are injurious to human health; some have acute ill effects while others pose a health hazard after prolonged period of exposure. Improper disposal of such wastes has resulted in the death of humans and animals through contamination of crops or water supplies.

The environmental damage caused by solid wastes mostly pertains to aesthetics. Uncontrolled dumping of urban wastes destroys the beauty of the countryside. Also, there is the danger of water pollution when the leachate from a refuse dump enters surface water or ground water resources. In addition, uncontrolled burning of open dumps can cause air pollution.

Solid waste disposal is at present limited to land and the ocean. Some of the wastes can be recovered and reprocessed, a procedure commonly known as recycling. However, before the wastes can be disposed of effectively, they must be collected efficiently. These activities, i.e., collection, disposal and/or recovery form a part of the solid waste management system.

STUDY QUESTIONS

1. What do you understand by greenhouse effect? Discuss the role of greenhouse gases in global warming.
2. Write in detail the processes that lead to ozone depletion. Discuss the health effects of ozone depletion.
3. What do you understand by El-Nino and ENSO? Discuss the climatic effects of El-Nino.
4. Define biodiversity. Discuss about hot spots of biodiversity.
5. Give a detailed account of solid waste pollution and its management with special reference to India.
6. Write short notes on the following:
    - (a) Loss of biodiversity
    - (b) Anthropogenic damage to ozone layer
    - (c) Biowealth of India
    - (d) Compositing of solid waste
    - (e) Public health aspects of solid waste

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3

Atmosphere and Air Pollution

INTRODUCTION

Everything present outside an individual is environment. The entire world and its materials can be grouped into non-living (abiotic) and living (biotic) components. Therefore, in other words, the environment is the sum total of abiotic and biotic conditions influencing the response of the particular organism (Kendeigh, 1974). The abiotic environment can be further classified into atmosphere, lithosphere and hydrosphere, whereas biotic environment is called biosphere. The gaseous envelope held to the planet by gravitational attraction of the earth is called atmosphere. The total mass of the atmosphere amounts to 5.7×10^{15} (5,700,000,000,000,000) tons of air. It blends at about 1000 km or so above the surface of the earth. Atmosphere is a reservoir of several life-supporting elements that serve many functions such as filtration of radiant energy from the sun, insulation of heat to check loss from earth's surface and stabilization of climatic conditions. Several biogeochemical cycles operate between organism and atmosphere. On the basis of physicochemical structure, the atmosphere can be further studied as follows.

ORIGIN OF ATMOSPHERE

Origin of atmosphere is related to the origin of earth itself. The earth was formed by the accretion of solid materials that condensed from the solar nebula. The atmosphere at that time was totally different from the atmosphere today. The evolution of atmosphere should therefore be studied in three stages to get an idea of how earth came into existence.

In the *first stage*, the earth by its gravitational force attracted gaseous constituents of the cosmic dust, viz. hydrogen, methane, ammonia, water vapour and noble gases. There was no oxygen at this stage and it was a reducing or hydrogen rich atmosphere. It lasted about 3.5×10^9 years ago.

The *second stage* of evolution of atmosphere lasted about 2×10^9 years ago. Volcanic eruptions took place during this period. Large quantities of magma, saturated with dissolved gases, moved towards the surface of the earth. They had to pass over iron present in the mantle. The gases such as nitrogen, hydrogen, hydrogen sulphide, carbon monoxide and water vapour existed in a reduced state. In later stages, when iron melted and drifted towards the core, ejected gases that did not pass over the iron and thus existed in the oxidized state. Any free oxygen that escaped from the interior of the earth combined with hydrogen, residual methane or ammonia. In the second stage also, there was no free oxygen in the atmosphere.

In the *third and present day* atmosphere, oxygen production began to exceed oxygen consumption. Two atmospheric phenomena contributed in the induction of oxygen. Firstly, it was the photochemical dissociation of water molecules. Water molecules absorbed ultraviolet rays and splitted into hydrogen and oxygen. The major part of oxygen was inducted by photosynthesis. This process began after the advent of life on the earth. Although oxygen began to accumulate in the atmosphere about 2×10^9 years ago, its build-up was quite gradual. However, the steep rise in oxygen level began only 0.6×10^9 years ago. The first multicellular marine organisms appeared during this period. They consumed phytoplankton and floated on water. With the decrease of phytoplankton, the number of heterotrophic bacteria also declined. This led to the increase in oxygen in the atmosphere.

VERTICAL STRUCTURE OF THE ATMOSPHERE

The vertical structure consisting of several layers of the atmosphere, determined primarily by the phenomena that occur there, is separated from one another by change in the slope of the graph of temperature vs. altitude. At the lowest level, the troposphere, the temperature decreases with increasing altitude until at the tropopause (10–12 km) the temperature is –70°C.

The next layer, the stratosphere, is characterised by increasing temperature, since near the top of the layer is a region where the ultraviolet solar radiation is absorbed by ozone. This makes the stratopause a warm area of the atmosphere and also provides an effective shield keeping away the harmful ultraviolet radiation from the ground (Fig. 3.1).

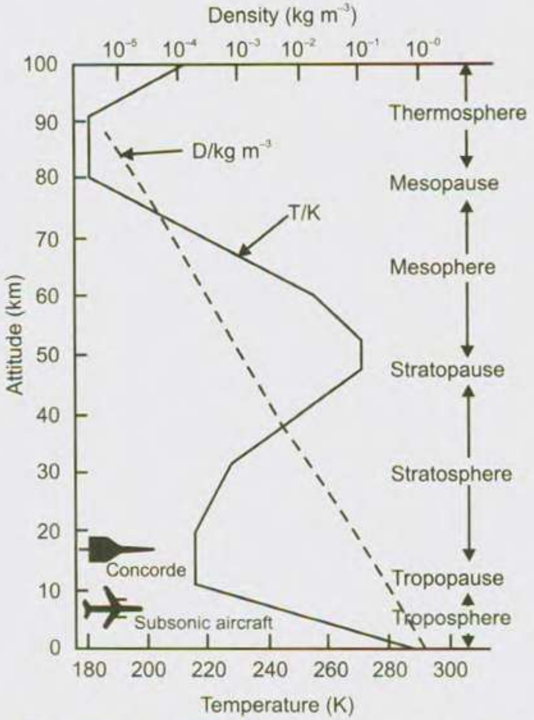


Figure 3.1: *The vertical structure of the atmosphere showing the location of troposphere and stratosphere.*

Troposphere. The lowest layer of atmosphere in which living organisms operate is called troposphere. It is the region of strong air movements and cloud formation characterized by steady decrease in temperature. It was a mixture of several gases which remained fairly in abundance. However, water vapour and dust occurred in troposphere in extremely variable concentrations. The composition of tropospheric air is shown in Table 3.1.

Table 3.1: *Composition of the tropospheric air*

Constituent	Percentage
Nitrogen	78.084
Oxygen	20.947
Argon	0.934
Carbon dioxide*	0.0314
Neon	0.001818
Helium	0.000524
Methane*	0.0002
Krypton	0.000114
Nitrous oxide	0.00005
Hydrogen	0.00005
Xenon	0.0000087
Ozone*	0.000001

*Percentage of these gases is highly variable.

Stratosphere. Stratosphere is the air mass extending from the uppermost level of the troposphere to uppermost level of stratosphere, about 50 km above the surface of the earth. Ozone present there forms an ozone layer called ozonosphere. It is formed from oxygen through a photochemical reaction where the oxygen molecule splits to form atomic oxygen.

$$O_2 + (h = \text{radiation}) = 2O$$

The atomic oxygen combines with molecular oxygen and ozone is formed.

$$O_2 + O = O_3$$

Although these reactions are reversible in nature, however, the percentage of ozone remains constant. Ozon forms an umbrella called ozone umbrella that absorbs the ultraviolet radiation from the sun. Moreover, it serves as a blanket in reducing the cooling rate of earth. Therefore, an equilibrium between ozone and rest of the air is a significant factor of the environment.

Mesosphere. Above stratosphere is the mesosphere, which is characterized by cold temperature and low atmospheric pressure. The temperature drops reaching a minimum of –95°C, 80–90 km above the earth's surface.

Thermosphere. Above the mesosphere is the thermosphere extending upto 500 km above the earth's surface. It is characterized by an increase in the temperature from the mesopause. Upper zone to thermosphere where ionization of molecular O_2 occurs is called the ionosphere.

Exosphere. The atmosphere above the ionosphere is called exosphere or outer space, which lacks atmospheric gases except hydrogen and helium and extends upto 32,190 km from the surface of the earth. It has very high temperature due to solar radiations.

CHEMICAL REACTIONS IN THE ATMOSPHERE

Photochemical Smog

Photochemical smog was first observed in Los Angeles, USA in the mid 1940's and since then the phenomenon has been detected in most major metropolitan cities of the world. The conditions for the formation of photochemical smog are air stagnation, abundant sunlight, and high concentrations of hydrocarbon and nitrogen oxides in the atmosphere. In India, Mumbai and Kolkata are ideal locations for the formation of photochemical smog, but it may be masked by smoke and sulphur dioxide.

Smog arises from photochemical reactions in the lower atmosphere by the interaction of hydrocarbons and nitrogen oxide released by exhausts of automobiles and some stationary sources. This interaction results in a series of complex reactions producing secondary pollutants such as ozone, aldehydes, ketones, and peroxyacyl nitrates. The reaction mechanisms are complex and are not fully understood.

A broad outline of the principal reactions that occur in a photochemical process is illustrated in Fig. 3.2. The starting mechanism is the absorption of ultraviolet light from the sun by NO_2. This causes the nitrogen dioxide to decompose into nitric oxide and highly reactive atomic oxygen.

$$NO_2 + h_n \rightarrow NO + O$$

The atomic oxygen initiates oxidizing processes or quickly combines with molecular oxygen to form ozone, which itself is reactive and acts as an oxidant:

$$\begin{aligned} O + O_2 + M &\rightarrow O_3 + M \\ O_3 + NO &\rightarrow NO_2 + O_2 \end{aligned}$$

In the above equation, an energy-absorbing molecule or particle (M) is required to stabilize O_3, or else it will decompose rapidly. Under normal conditions, the ozone formed will be quickly removed by reaction with NO to provide NO_2 and O_2; however, when hydrocarbons are present in the atmosphere, this mechanism is partially eliminated since NO reacts with the hydrocarbon radical, peroxyacyl (RCO_3) and as a result, ozone concentration builds up to dangerous levels.

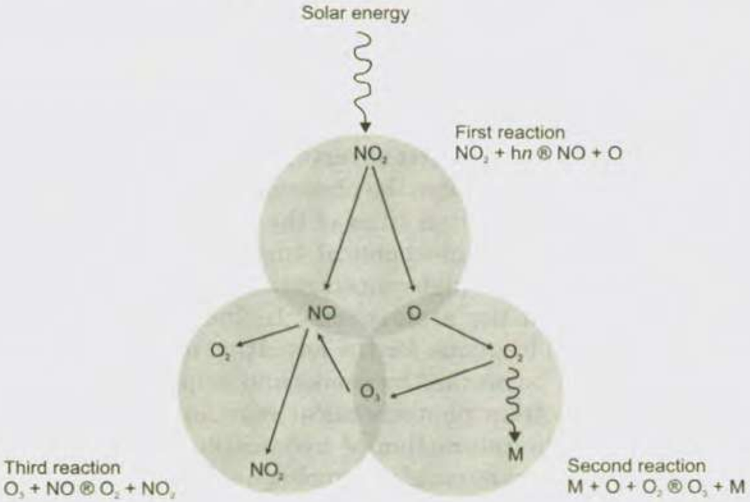


Figure 3.2: The cycle of chemical reactions initiated by NO_2.

In the absence of hydrocarbons, the cycle initiated by NO_2 consists of three reactions. First, NO_2 absorbs solar energy, dissociating into a molecule of NO and a free oxygen atom, which is highly reactive. Second, the free oxygen atom then reacts with an ordinary oxygen molecule (O_2) to form ozone (O_3). Since the ozone formed in this way is unstable, having too much energy to exist for very long, it dissipates this excess energy by colliding with another molecule, transferring the excess as kinetic energy to the other molecule. If another molecule is not handled at the proper time, the ozone molecule will dissociate, leaving the free oxygen atom to try again. When a stable ozone molecule is formed, it can participate in the third reaction, reacting with the NO molecule produced in the first reaction, which forms nitrogen dioxide again. In this way all the molecular species exist in an equilibrium, and the primary result is that the energy absorbed by the NO_2 is transferred to the air as kinetic energy, warming the air.

Hydrocarbons, indicated by symbol HC, compete for free oxygen released by NO_2 decomposition to form oxygen-bearing free radicals such as the acyl radical.

$HC + O \rightarrow RCO^{\cdot}$ (acyl radical)

This radical takes part in a series of reactions involving the formation of still more reactive species, which in turn react with O_2, hydrocarbons and nitric oxide.

$RCO^{\cdot} + O_2 \rightarrow RCO_3^{\cdot}$ (peroxyacyl radical)
$RCO_3^{\cdot} + HC \rightarrow RCHO^{\cdot}$ (aldehydes), R_2CO (ketones)
$RCO_3^{\cdot} + NO \rightarrow RCO_2^{\cdot} + NO_2$
$RCO_3^{\cdot} + O_2 \rightarrow RCO_2 + O_3$

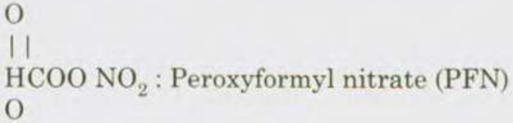
Above equations are termination reactions forming aldehydes and ketones; however, the peroxyacyl radical reacts with NO and O_2 to produce another oxidized hydrocarbon radical (RCO_2) as well as more NO_2 and O_3. Further, RCO_2 radical can react with NO to generate even more NO_2.

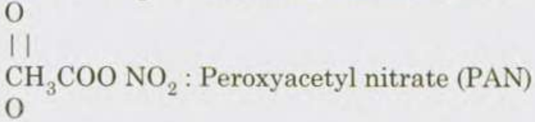
$RCO_2^{\cdot} + NO \rightarrow RCO^{\cdot} + NO_2$

The NO level in the atmosphere eventually drops off with the accumulation of NO_2 and O_3. When reactions such as these increase the NO_2 level sufficiently, another reaction begins to compete for the peroxyacyl radical.

$RCO_3^{\cdot} + NO_2 \rightarrow RCO_3NO_2$ (PANs)

The end products are known as peroxyacyl nitrates or PANs. Numerous PANs could be formed, corresponding to the different possible R groups. Three of the common members of PAN family are:


$\overset{\overset{O}{||}}{H}COO\ NO_2$: Peroxyformyl nitrate (PFN)


$\overset{\overset{O}{||}}{C}H_3COO\ NO_2$: Peroxyacetyl nitrate (PAN)


$\overset{\overset{O}{||}}{C}_6H_5 - COONO_2$: Peroxybenzoyl nitrate (PBzN)

The ozone reacts with the hydrocarbons to generate more aldehydes and ketones.

$$HC + O_3 \rightarrow RCO_2^{\cdot} + RCHO, R_2CO$$

The above equations represent in a broad sense the nature of the overall photochemical reactions leading to formation of smog, and they are by no means the only important mechanisms. It has been observed that carbon monoxide and sulphur dioxide also play a significant role in the process of formation of smog by strongly interacting with many species present in the smog and accelerate the oxidation processes. For example, carbon monoxide does this through a series of reactions whose net effect is to convert CO, NO and O_2 into CO_2 and NO_2 thus accelerating the oxidation of NO. First, CO is oxidized to CO_2 by the OH radical. In the smoggy atmosphere, the OH radical may be produced when aldehydes are attacked by atomic oxygen.

$$\begin{aligned} O + CH_3\,CHO &\rightarrow CH_3\,CO + OH^{\cdot} \\ CO + OH^{\cdot} &\rightarrow CO_2 + H^{\cdot} \\ H^{\cdot} + O_2 + M &\rightarrow HO_2^{\cdot} \end{aligned}$$

The H radical reacts with O_2 to form the hydroperoxyl radical HO_2, which is a principal agent for the rapid conversion of NO into NO_2.

$$HO_2 + NO \rightarrow OH^{\cdot} + NO_2$$

The overall reaction is

$$CO + O_2 + NO \rightarrow CO_2 + NO_2$$

This sequence of reactions provides another route for the oxidation of NO without the participation of O_3.

Similarly, the reaction of SO_2 with the HO_2 radical may be an important step in the mechanism of the oxidation of SO_2.

$$HO_2^{\cdot} + SO_2 \rightarrow OH^{\cdot} + SO_3$$

In addition, the hydrocarbon radicals may give off an oxygen atom to form SO_3, which in turn is converted to H_2SO_4 droplets resulting in the formation of haze.

AIR POLLUTION

Air pollution may be defined as any atmospheric condition in which certain substances are present in such concentrations that they can produce undesirable effects on man and his environment. These substances include gases (sulphur oxides, nitrogen oxides, carbon monoxide, hydrocarbons, etc.), particulate matter (smoke, dust, fumes, aerosols), radioactive materials and many others. Most of these substances are naturally present in the atmosphere in low (background) concentrations and are usually considered to be harmless. The background concentrations of various components of dry air near sea level and their estimated amount are given in Table 3.2. Thus, a particular substance can be considered as air pollutant only when its concentration is relatively high compared with the background value and causes adverse effects. For example, if sulphur dioxide, is present in the atmosphere in concentrations greater than the background value of 2×10^4 ppm and causes measurable effects on humans, animals, plants, or property, then only it is classified as an air pollutant.

Table 3.2. Comparison of the amounts of anthropogenic pollutants with the amounts naturally present in dry, clean air

Pollutant	Amount (millions of tons of pollutants)	
	Anthropogenic (per year)	Dry, clean air
Particulates	269	–
SO_2	132	2
NO_2	48	8
CO	400	500

The concentration of a pollutant in the atmosphere can be expressed in a number of ways involving units of weights or volume per unit weight or volume of air. Four concentration scales are generally used to describe the concentrations of either gaseous or particulate pollutants.

The first mass concentration, ω_p, defined as the ratio of the mass of pollutant to the mass of air plus mass of pollutant, i.e.

$$\omega_p = \frac{mp}{m_a + m_p}$$

where m_p is the mass of the pollutant and m_a is the mass of pure air in a given volume of air-pollutant mixture. The second concentration scale is the volume consideration, y_p, defined as the ratio of the volume of pollutant to the volume of air plus volume of pollutant:

$$y_p = \frac{V_p}{V_a + V_p}$$

The third concentration scale is the volume concentration in parts per million (ppm), y_{ppm}; which can be represented as:

$$y_{ppm} = y_p ´ 10^6$$

CLASSIFICATION OF AIR POLLUTANTS

The variety of matter emitted into the atmosphere by natural and anthropogenic sources is so diverse that it is difficult to classify air pollutants neatly. However, usually they are divided into two categories i.e., *primary pollutants* and *secondary pollutants*. The primary pollutants are those that are emitted directly from the sources. Typical pollutants included under this category are particulate matter such as ash, smoke, dust, fumes, mist and spray; inorganic gases such as sulphur dioxide, hydrogen sulphide, nitric oxide, ammonia, carbon monoxide, carbon dioxide, and hydrogen fluoride; olefinic and aromatic hydrocarbons; and radioactive compounds. The secondary pollutants are those that are formed in the atmosphere by chemical interactions among primary pollutants and normal atmospheric constituents. Pollutants such as sulphur trioxide, nitrogen dioxide, PAN (peroxyacetyl nitrate), ozone, aldehydes, ketones, and various sulphate and nitrate salts are included in this category.

Of the large number of primary pollutants emitted into the atmosphere, only a few are present in sufficient concentrations to be of immediate concern. These are the five major types—

particulate matter, sulphur oxides, oxides of nitrogen, carbon monoxide, and hydrocarbons. Carbon dioxide is generally not considered an air pollutant, but due to its increased global background concentration, its influence on global climatic patterns is of great concern.

Secondary pollutants are formed from chemical and photochemical reactions in the atmosphere. The reaction mechanisms and various steps involved in the process are influenced by many factors such as concentration of reactants, the amount of moisture present in the atmosphere, degree of photoactivation, meteorological forces, and local topography.

PROPERTIES OF AIR POLLUTANTS

(a) Particulate Matter

In general, the term 'particulate' refers to all atmospheric substances that are not gases. They can be suspended droplets or solid particles or mixtures of the two. Particulates can be composed of inert or extremely reactive materials ranging in size from 100 mm down to 0.1 mm and less. The inert materials do not react readily with the environment, nor do they exhibit any morphological changes as a result of combustion or any other process, whereas the reactive materials could be further oxidized or may react chemically with the environment.

The classification of various particulates may be made as follows:

Dust. It contains particles of the size ranging from 1 to 200 mm. These are formed by natural disintegration of rock and soil or by the mechanical processes of grinding and spraying. They have large settling velocities and are removed from the air by gravity and other inertial processes. Fine dust particles act as centres of catalysis for many of the chemical reactions taking place in the atmosphere.

Smoke. It contains fine particles of the size ranging from 0.01 to 1 mm, which can be liquid or solid, and are formed by combustion or other chemical processes. Smoke may have different colours depending on the nature of the material burnt.

Fumes. These are solid particles of the size of about 0.1 mm and are normally released from chemical or metallurgical processes.

Mist. It is made up of liquid droplets generally smaller than 10 mm, which are formed by condensation in the atmosphere or are released from industrial operations.

Fog. It is the mist in which the liquid is water and is sufficiently dense to obscure vision.

Aerosol. Under this category are included all air-borne suspensions, either solid or liquid; these are generally smaller than 1 mm.

Particles in the size range 1–10 mm have measurable settling velocities but are readily stirred by air movements, whereas particles of size 0.1–1 mm have small settling velocities. Those below 0.1 mm, a submicroscopic size found in urban air, undergo random Brownian motion resulting from collisions among individual molecules. Of all the different types of particulates in the atmosphere, the presence of trace elements such as cadmium, lead, nickel and mercury may constitute the greatest health hazard. Many of the trace metals are toxic and are concentrated in the finest of particulate matter in a variety of combined forms such as oxides, hydroxides, sulphates, and nitrates.

(b) Gases

(i) Oxides of sulphur

The most important oxide emitted by pollution sources is sulphur dioxide (SO_2). SO_2 is a colourless gas with a characteristic, sharp, pungent odour. It is moderately soluble in water (11.3 g/100 cm) forming weakly acidic sulphurous acid (H_2SO_3). It is oxidized slowly in clean air to sulphur trioxide. In a polluted atmosphere, SO_2 reacts photochemically or catalytically with other pollutants or normal atmospheric constituents to form sulphur trioxide, sulphuric acid and salts of sulphuric acid.

Sulphur trioxide (SO_3) is generally emitted along with SO_2, with 1–5 per cent concentration of that of SO_2. SO_3 rapidly combines with moisture in the atmosphere to form sulphuric acid, which has a low dew point. Both SO_2 and SO_3 are relatively quickly washed out of the atmosphere by rain, or they settle out as aerosols. This is the reason why SO_2 mass in clean dry air is so small compared to annual emissions from anthropogenic sources. The major source of sulphur dioxide is the combustion of fossil fuels containing sulphur. These are predominantly coal and fuel oil, since natural gas, petrol, and diesel fuels have a relatively low sulphur content.

The adverse effects of sulphur dioxide itself include damage to human respiratory function, especially when exposure is in conjunction with particulates, as in the London smogs of the 1950's. Sulphur dioxide is also damaging to plants at modestly elevated concentrations. Whilst Britain does not set ambient air quality standards for pollutants, the US environmental Protection Agency standards for this pollutant are 80 μgm^{-3} (annual average) and 365 μgm^{-3} (24 h average) and the World Health Organization long-term goal is 4060μgm^{-3} (annual mean) with 98% of measurements below 100–150 $\mu g\ m^{-3}$.

Chemical analysis of sulphur dioxide: Sulphur dioxide may be determined by many procedures of widely differing sensitivity and specificity. The method used in the UK 'National Survey of Air Pollution' involves absorption of the sulphur dioxide in hydrogen peroxide. The resultant acid is determined by acid-base titration or conductivity measurement. Although acidic or basic compounds interfere, these techniques can yield useful results in urban areas where sulphur dioxide concentrations are high and levels of interfering substances are low. In rural areas this is not the case due to natural production of ammonia, and misleading results are obtained. The West-Gaeke technique, in which sulphur dioxide is collected by reaction with potasium or sodium tetrachloromercurate(II), forming the disulphitomercurate(II) and then determined, colorimetric ally, after addition of acidic pararosaniline methyl sulphonic acid, has been refined to the point where the effects of known interfering substances have been minimized or eliminated.

$$[HgCl_4]^{2-} + 2SO_2 + 2H_2O \rightarrow [Hg(SO_3)_2]^{2-} + 4Cl^- + 4H^+$$

By using flow systems, continuous monitors have been built using this reaction, but the response time is relatively long, of the order of several minutes, and shortlived concentration peaks are not accurately measured.

In the flame photometric sulphur analyser, gaseous sulphur compounds are burned in a reducing hydrogen-air flame and the emission of the S_2 species at 394 nm is measured. The technique has a very fast response as polluted air may be passed directly to the flame. The sensitivity is similar for all volatile sulphur compounds and in urban air the level of total volatile sulphur, as given by a flame photometric analyser, approximates closely to the sulphur dioxide level. When several sulphur compounds are present in air at comparable concentrations, gas chromatographic separation is possible from a small air sample at ppb levels using the flame photometric analyser as detector.

An alternative technique is specific for measurement of sulphur dioxide at levels down to I ppb. Fluorescence, excited by radiation in the region of 214 nm, is measured (Fig. 3.3) and a very wide linear range of response is found. Instruments covering the range of 1–5000 ppm and 0–0.5 ppm of SO_2 are available. The commonly used techniques for analysis of SO_2 and other pollutants are summarized in Table 3.3, and are described in more detail elsewhere.

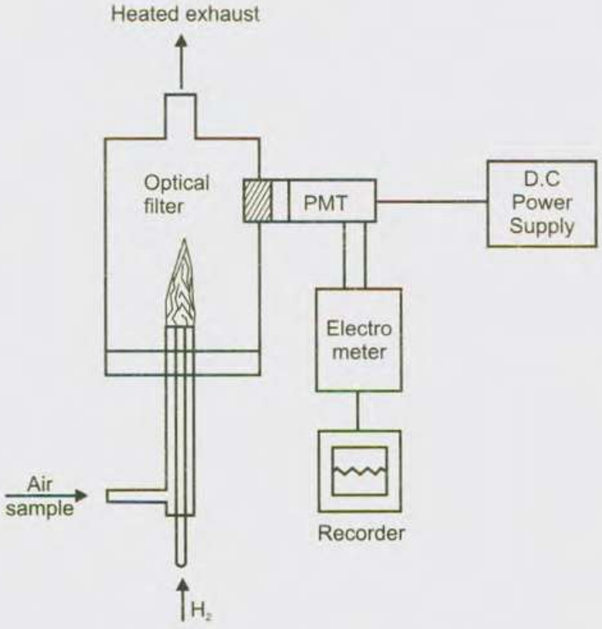


Figure 3.3: *Flame photometric analyzer*

Table 3.3: *Summary of commonly employed methods for measurement of air pollutants*

Pollutant	Measurement Technique	Sample Collection Period	Response time (continuous technique)	Minimum detectable concentrations
Sulphur dioxide	Absorption in H_2O_2 and titration	24h		2ppb
	Absorption intetrachloromercuratef/ spectrophotometry	15min		10 ppb
	Flame photometric analyser		25 s	0.5 ppb
	Gas phase fluorescence	2min	0.5 ppb	
Oxides of nitrogen	Chemiluminescent reaction with ozone		1.0	0.5 ppb
Total hydrocarbons	Flame IOnization analyser		0.5 s	10 ppb C
Specific hydrocarbons	Gas chromatographyf flame ionization detector	b		< 1 ppb
Carbon monoxide	Catalytic methanation FID	c		10 ppb
	Electrochemical cell		25 s	1 ppm
	Non-dispersive infrared		5s	0.5 ppm
Ozone	Chemil uminescen t reaction with ethene		3s	1 ppb
	V.v. absorption		30 s	1 ppb
Peroxyacetyl nitrate	Gas chromatographyf electron capture detection	c		1 ppb
Particulates	High volume sampler	24h		5 μm^{-3}
	-gauge	minfhours		5 $\mu g\ m^{-3}$

(a) Time taken for a 90 per cent response to an instantaneous concentration change

(b) Grab samples of air collected in an inert container and concentrated prior to analysis

(c) Instantaneous concentrations measured on a cyclic basis by flushing the contents of a sample loop into the instrument.

(ii) Nitrogen oxide

Of the six or seven oxides of nitrogen, only three—nitrous oxide (N_2O), nitric oxide (NO), and nitrogen dioxide (NO_2)—are formed in any appreciable quantities in the atmosphere. Often NO and NO_2 are analyzed together in air and are referred to as NO_2.

Nitrous oxide is a colourless, odourless, nontoxic gas present in the natural atmosphere in relatively large concentrations (0.25 ppm). The major source of N_2O in the atmosphere is the biological activity of the soil and there are no significant anthropogenic sources. It has a low reactivity in the lower atmosphere and is generally not considered an air pollutant.

Nitric oxide is a colourless, odourless gas produced largely by fuel combustion. It is oxidized to NO_2 in a polluted atmosphere through photochemical secondary reactions. Nitrogen dioxide is a brown pungent gas with irritating odour, which can be detected at concentrations of about 0.12 ppm. It absorbs sunlight and initiates a series of photochemical reactions. Small concentrations of NO_2 have been detected in the lower stratosphere; NO_2 is probably produced by the oxidation of NO by ozone. Nitrogen dioxide, which is emitted mainly by fuel combustion and nitric acid plants, is of major concern as a pollutant. The major source of NOx is the high temperature combination of atmospheric nitrogen and oxygen, in combustion processes, there being also a lesser contribution from combustion of nitrogen contained in the fuel.

Typical ambient air concentrations of *NOx* are normally within the range 5–100ppb (roughly 10–200/lgm^{-3}) in urban areas and <20ppb at rural sites. The US Environmental Protection Agency (USEPA) ambient air quality standard for NO_2 is 100/lgm^{-3} (annual average). The EEC directive limit is a 98 percentile value of 105 ppb hourly average, not to be exceeded in a year, and guide values are 71 ppb and 26 ppb as 98 and 50 percentiles hourly averages, not to be exceeded in a year. The direct effects of exposure to oxides of nitrogen include human respiratory tract irritation and damage to plants. Indirect effects arise from the essential role of NO_2 in photochemical smog reactions and its oxidation to nitric acid contributing to acid rain problems.

Analysis of oxides of nitrogen: Manual wet chemical procedures for NOx are based upon conversion of NO_2 to nitrite, which is then determined typically by diazotization and azo dye formation. This, however, was found to be very problematic when reliable sources of NO_2 calibration gas became available, since the collection efficiency for NO_2 was found to be variable, and the stoichiometry of the NO_2 to nitrite conversion uncertain.

This finding led to further method development and introduction of improved procedures such as that involving the use of arsenite in the collection solution to enhance the formation of nitrite. Another problem has been associated with the nonquantitative conversion of NO to NO_2 in order to determine NO_x.

Instrumental analysers not subject to these problems have now been available for a good number of years. The currently favoured technique for determination of oxides of nitrogen is based upon the chemiluminescent reaction of nitrogen oxide and ozone to give an electronically excited nitrogen dioxide, which emits light in the 600–3000 nm region with a maximum intensity near 1200 nm:

$$\begin{aligned} NO + O_3 &\rightarrow NO_2^* + O_2 \\ NO_2^* &\rightarrow NO_2 + hv \end{aligned}$$

In the presence of excess ozone generated within the instrument, the light emission varies linearly with the concentration of nitrogen oxide from 1 ppb to l04 ppm. The apparatus is shown in Fig. 3.4.

(iii) Carbon monoxide

It constitutes the single largest pollutant in the urban atmosphere. CO is colourless, odourless, and tasteless, and has

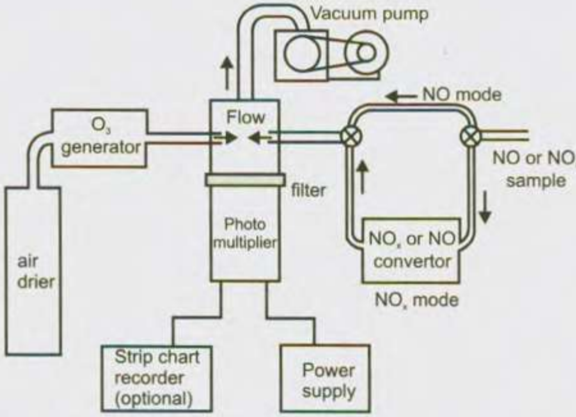


Figure 3.4: *Chemiluminescent analyzer for oxides of nitrogen*

a boiling point of 192°C. It has a strong affinity towards the hemoglobin of the blood and is a dangerous asphyxiant. The rate of oxidation of carbon monoxide to carbon dioxide in the atmosphere seems to be very slow, because mixtures of CO and O_2 exposed to sunlight for several years have been found to remain almost unchanged. Carbon monoxide is present in small concentrations (0.1 ppm), the main sources of CO in the urban air being smoke and exhaust fumes of burning coal, gas or oil. The USEPA ambient air quality standard for CO is 9 ppm (8 hour average) and 35 ppm (1 hour average).

Chemical analysis of carbon monoxide: Non-dispersive infra-red is used to measure carbon monoxide in street air where levels encountered normally lie within the range 1–50 ppm. Because of partial overlap of absorption bands, carbon dioxide and water vapour interfere. The latter may be removed by passing the air sample through a drying agent, and the former interference by interposing a cell of carbon dioxide between the sample and reference cells and the detectors. Using a long-path cell, the i.r. absorbance of polluted air at the wavelength corresponding to the C–O stretching vibration is continuously determined relative to that of reference air containing no CO. This is achieved without dispersion of the i.r. radiation by using cells containing CO at a reduced pressure as detectors for two beams, which are chopped at a frequency of about 10Hz and passed respectively through sample and reference cells. Absorption of radiation by the CO causes a differential pressure between the two detector cells, which is sensed by a flexible diaphragm between them and used to generate an electrical signal.

A gas chromatographic technique, although not allowing continuous measurement of CO, has a substantially higher sensitivity. The basis of the method is catalytic reduction of the carbon monoxide to methane and detection by flame ionization detector (FID) (Fig. 3.5). This principle is used in commercial instruments, which measure methane, carbon monoxide, and total hydrocarbons. Hydrogen carrier gas flushes a small air sample from a sample loop through a stripper column, (Cl) packed with an adsorbent porous polymer, for sufficient time to allow passage of methane and carbon monoxide but not the heavier compounds which are subsequently removed by back-

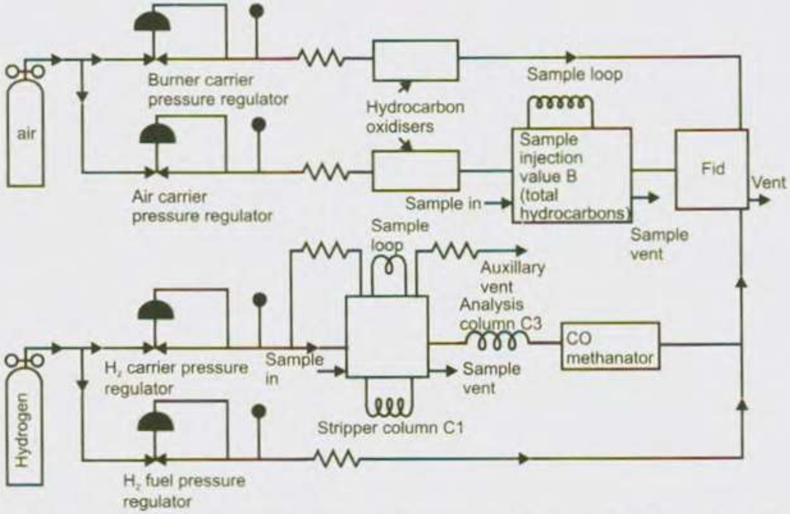


***Figure 3.5**: Analyzer giving sequential measurements of methane, carbon monoxide and total hydrocarbons*

flushing. Passage of the methane and carbon monoxide through a chromatographic column containing molecular sieves (C3) causes separation of these compounds, which are passed to the FID via a catalytic methanator. Sub-ppm levels are readily determined. Modification of the instrument allows passage of C2 hydrocarbons through the stripper column, and these are separated on a second column of porous polymer and passed directly to the detector. Total hydrocarbons are determined by passage of a 10 cm^3 air sample directly into the FID (valve B). The carrier gas is air, purified by catalytic oxidation of impurities and this, rather than more conventional carrier gases, eliminates problems resulting from radical changes in flame characteristics upon introduction of the polluted air sample into the detector.

An analyser for continuous determination of carbon monoxide at levels down to 1 ppm uses an electrochemical cell. Gas diffuses through a semi-permeable membrane into the cell, and at an electrode CO is oxidized to CO_2 at a rate proportional to the concentration of CO in the air. The response time is fairly short and interferences from other air pollutants at normally encountered levels are minimal. Analysers based upon electrochemical cells are also available for measurement of sulphur dioxide and oxides of nitrogen.

(iv) Carbon dioxide

Increasingly, CO_2 is viewed as an air pollutant because of its importance as a 'greenhouse gas.' Its sources lie in animal and plant respiration, and anoxic decomposition processes and the main sink is in photosynthesis. It may be both absorbed or released by the oceans, which contain an appreciable concentration of bicarbonate. The source drawing most attention, fossil fuel combustion, is a relatively minor one, but a small imbalance in the CO_2 cycle is leading to a steady increase in atmospheric concentration, exemplified in Fig. 3.6.

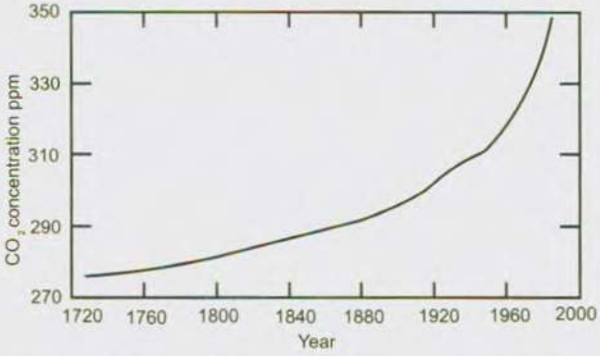


Figure 3.6: *Trends in concentrations of atmospheric carbon dioxide.*

(c) Hydrocarbons

The gaseous and volatile liquid hydrocarbons are of particular interest as air pollutants. Hydrocarbons can be saturated or unsaturated, branched or straight-chain, or can have a ring structure as in the case of aromatics and other cyclic compounds. In the saturated class, methane is by far the most abundant hydrocarbon constituting about 40 to 80 per cent of the total hydrocarbons present in an urban atmosphere. The unsaturated class includes alkenes (olefins) and acetylenes. Among the alkenes the prominent pollutants are ethylene and propene. The first member of the aromatic class is benzene, but some of its substituted derivatives such as toluene and *m*-xylene are usually present in larger concentrations in the urban atmosphere.

Terpenes are a particular class of volatile hydrocarbons emitted largely by natural sources. These are cyclic non-aromatic hydrocarbons formed in pine tar and in other wood sources.

The hydrocarbons in air by themselves alone cause no harmful effects. They are of concern because the hydrocarbons undergo chemical reactions in the presence of sunlight and nitrogen oxides forming photochemical oxidants of which the predominant one is ozone. Methane has very low photochemical activity as compared to that of other hydrocarbons. For this reason, it is the non-methane hydrocarbon concentration that is of interest while considering air pollution. Because of the great diversity of hydrocarbon compounds in polluted air, it is not possible to make a clear statement on toxic levels. Some individual compounds such as benzene are of concern due to human toxicity, whilst others, particularly ethene, which is a plant growth hormone, may affect the development of crops.

Chemical analysis of hydrocarbons: Analysis of total hydrocarbons or non-methane hydrocarbons is complicated by the great complexity of the mixture present and as a rule no attempt is made to analyse every compound individually. At one time, use of non-dispersive infra-red (see section on CO) was common. This utilized hexane vapour in the detector and thus responded to compounds whose infra-red spectrum overlapped with that of hexane, most notable in the regions of the C-H stretching vibration. Since not all hydrocarbons absorb at the same wavelength and absorption intensities differ, the sensitivity per carbon atom in the molecule is similar for alkanes other than methane, but is substantially less for alkenes and aromatics and almost nil for ethyne.

The universal choice nowadays for total hydrocarbon analysis is the flame ionization analyzer, based upon the use of ambient air as oxidant in an air/hydrogen flame ionization detector in which the presence of hydrocarbons leads to enhanced conductivity of the flame. Sensitivity per carbon atom of individual hydrocarbons varies little, whilst oxygenated and halogenated compounds cause a lower response. Water vapour, carbon dioxide, and carbon monoxide do not significantly affect the reading. The instrument is calibrated with methane and results are reported as ppb C, or parts per billion carbon since 25 ppb butane (100 ppb C), 50 ppb ethane (100 ppb C), and 100 ppb methane (100 ppb C) give the same response. Methane is determined in such instruments by selectively scrubbing all other hydrocarbons from the air stream prior to analysis and the non-methane hydrocarbon concentration is derived by difference.

Determination of specific hydrocarbons in ambient air normally requires a pre-concentration stage in which air is drawn through an adsorbent such as a porous polymer or activated carbon, or a tube where freeze-out of the compounds by reduced temperature occurs, followed by injection into a gas liquid chromatograph. Excellent separations of many compounds have been achieved, the best results coming from the use of capillary columns. Detection may be by flame ionization, or by passage into a mass spectrometer (GC-MS), the latter techniques allowing a more positive identification of individual compounds.

SECONDARY POLLUTANTS

Ozone

Atmospheric reactions involving oxides of nitrogen and hydrocarbons cause the formation of a wide range of secondary products. The most important of these is ozone. In severe photochemical smogs, such as that's occur in Southern California, levels of ozone may exceed 400 ppb.

We do not experience the classic Los Angeles type of smog. Nonetheless, the same chemical processes give rise to elevated levels of ozone, often in a regional phenomenon extending over hundreds of miles simultaneously. Thus hydrocarbon and NO emissions over wide areas of Europe react in the presence of sunlight causing large scale pollution, which is further extended by atmospheric transport of the ozone. The phenomenon is crucially dependent upon meteorological conditions, and hence, in Britain is observed on only perhaps 10–30 days in each year on average. Concentrations of ozone measured at ground-level commonly exceed 100 ppb during such 'episodes' and have on one severe occasion been observed to exceed 250 ppb in Southern England. These levels may be compared with a background of ozone at ground-level arising from downward diffusion of stratospheric ozone and general tropospheric production of 20–50 ppb. This is seen in Fig. 3.7 showing measurement data from North West England.

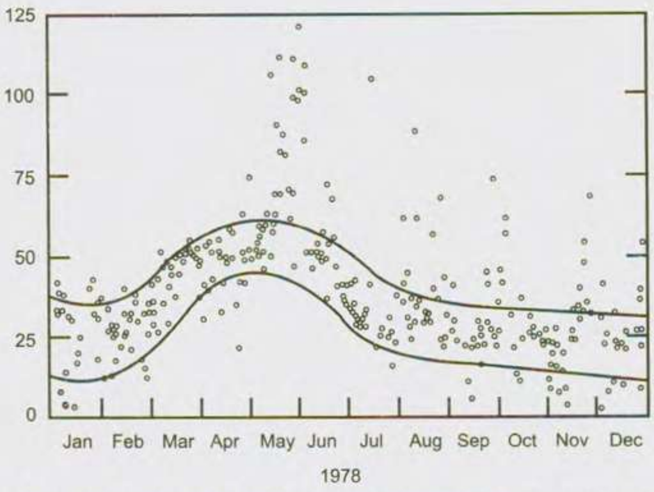


Figure 3.7: *Daily maximum hourly ozone concentrations at a rural site near Heysham, Lancs during 1978. The dashed lines represent an estimated "background"*

There is evidence of adverse health effects arising from human exposure to ozone. The USEPA ambient air quality standard is 120 ppb, not to be exceeded as an hourly average more than once per year. Damage to crop plants may occur at levels below this, with some varieties showing adverse effects at levels as low as 50 ppb. Economic losses to crops in the United States due to ozone damage are considerable.

Chemical analysis of ozone: No specific wet chemical method is available for ozone analysis and concentrations of 'oxidant' in the air have been determined by measurement of the capacity of an air sample to oxidize neutral buffered potassium iodide. Thus the method is sensitive not only to ozone but also to other oxidizing substances in the air including peroxyacyl nitrates and nitrogen dioxide, with a lesser sensitivity. The overall reaction with ozone was assumed to be as below with a consequent stoichiometry of I_2/O_3 equal to 1.0.

$$\begin{aligned} O_3 + 2H^+ + 2I^- &\rightarrow I_2 + H_2O + O_2 \\ I_2 + KI &\rightarrow KI_3 \end{aligned}$$

Some workers, however, have found a stoichiometry for I_2/O_3 of 1.5 and observed an enhanced formation of iodine and a reduced oxygen formation with increasing pH and postulated a more complex mechanism. The feasibility of iodide oxidation to iodate has been shown and the possibility of catalysis of this reaction by a glass frit. Hence, in addition to the lack of specificity of the reagent, the stoichiometry of the reaction with ozone is in doubt. The use of a borate, rather than a phosphate buffer, has been shown to overcome many of these problems.

Appropriate chemical filters improve the selectivity of methods based upon the oxidation of neutral buffered halide. Sulphur dioxide produces a negative interference equal to the equivalent molar concentration of oxidant and may be eliminated by incorporating a chromic acid paper absorber in the sampling line. The chromic acid does, however, oxidize nitrogen oxide to nitrogen dioxide causing further interference in the presence of NO.

Ozone may be continuously and specifically determined by measurement of the light emitted by the chemiluminescent reaction of ozone and ethane:

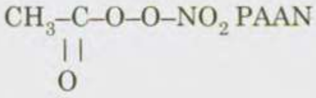
$$\begin{array}{ll} C_2H_4 + O_3 & \rightarrow \text{Ozonide ? } CH_2O^* \\ CH_2O^* & \rightarrow CH_2O + h\upsilon \end{array}$$

Emission is centered on 435 nm and hence no interference from the reaction of ozone and nitrogen oxide occurs. The method is sensitive to as little as I ppb of ozone.

The u.v. absorption of ozone at 254 nm may be used for its determination at levels down to I ppb. Interferences from other u.v. absorbing air pollutants such as mercury and hydrocarbons may be minimized by taking two readings. The first reading is of the absorbance of an air sample after catalytic conversion of ozone to oxygen and the second is of an unchanged air sample, the difference in absorbance being due to the ozone content of the air. Available instruments perform this procedure automatically and give read-out in digital form. Although truly continuous measurement of ozone levels is not possible, response is fast and readings may be taken at intervals of less than one minute.

Peroxyacetyl Nitrate (PAN)

PAN is a product of atmospheric photochemical reactions and is characteristic of photochemical smog.



$$CH_3-\underset{\underset{O}{||}}{C}-O-O-NO_2 \text{ PAAN}$$

Levels in Southern California lie typically within the range 5–50 ppb on smoggy days. In Europe, the formation is far less favoured and concentrations are more usually < 10 ppb.

Chemical analysis of peroxyacetyl nitrate: PAN may be determined by long-path i.r. measurements, the greatest sensitivity being achieved when Fourier transform methods are used. The most sensitive and specific routine technique involves gas chromatographic separation and detection of specific peroxyacyl nitrates by electron capture. The detection limit of below I ppb permits it to be used as a direct atmospheric monitor under circumstances of high pollution.

Organic Gases and Vapour Analysis

The best method is GLC. Lighter organics are determined by adsorption chromatography. CH_4 is determined at ppb level by GLC. 3–4 benzopyrene and polycylic compounds are determined by GLC. HCHO is a component of photochemical smog and is determined with chromotropic acid in H_2SO_4. Olefins and acroleins are also analyzed by gas chromatography. It is always not possible to get definite information by GLC, but hyphenated GC-MS offers useful information in characterization of organic pollutants.

It will be noted that for rapid analysis of gaseous pollutants in Indian environment, the best method is spectrophotometry. The methods are simple, inexpensive, with availability of a plethora of organic ligands. In the next chapter we would consider methods for continuous measurement of air pollutants. These in fact can be termed as monitoring methods.

INDOOR AIR QUALITY

Until rather recently, the emphasis on air quality evaluation has centered upon the outdoor environment. Recently, however, it has become clear that exposure to pollutants indoors may be very important.

Pollutants with indoor sources may build up to appreciable levels because of the slowness of air exchange. An example is oxides of nitrogen from gas cookers and flueless gas and kerosene heaters, which can readily exceed outdoor concentrations. Kerosene heaters can also be an important source of carbon monoxide and sulphur dioxide. Building materials and furnishings can also release a wide range of pollutants, such as formaldehyde from chipboard and hydrocarbons from paints, cleaners, adhesives, timber and furnishings. The tendency towards lower ventilation levels (energy efficient houses) has tended to exacerbate this problem.

Pollutants with a predominantly outdoor source may be reduced to rather low levels indoors due to the high surface area/ volume ratios indoors leading to extremely efficient dry deposition of pollutants such as ozone and sulphur dioxide.

POLLUTANT CYCLES

Pollutants are emitted from *sources* and are removed from the atmosphere by *sinks*. Most pollutants have both natural and man made sources; although the natural source is often of sizeable magnitude in global terms, on a local scale in populated areas pollutant sources are usually predominant. Sink processes include both dry and wet mechanisms. Dry deposition involves the transfer and removal of gases and particles at land and sea surfaces without the intervention of rain or snow. For gases removed at the surface, dry deposition is driven by a concentration gradient caused by surface depletion; for particles this mechanism operates in parallel with gravitational settling of the large particles. The efficiency of dry deposition is described by the *deposition velocity*, Vg, defined as

$$V_g(\mathrm{ms^{-1}}) = \frac{\text{Flux to surface } (\mu\ \mathrm{g\ m^{-2}s^{-1}})}{\text{Atmospheric concentration } (\mu\ \mathrm{g\ m^{-2}s^{-1}})}$$

Some typical values of deposition velocity are given in Table 3.4. For gases, such as sulphur dioxide, which have a fairly high Vg, dry deposition has little influence upon near-surface concentrations, but may appreciably influence ambient levels at large downwind distances.

Table 3.4 *Some typical values of deposition velocity*

Pollutant	Surface	Deposition Velocity (cm s^{-1})
SO_2	Grass	1.0
SO_2	Ocean	0.5
SO_2	Soil	0.7
SO_2	Forest	2.0
O_3	Dry grass	0.5
O_3	Wet grass	0.2
O_3	Snow	0.1
HNO_3	Grass	2.0
CO	Soil	0.05
Aerosol (<2.5 μm)	Grass	0.15

Wet deposition describes scavenging by precipitation (rain, snow, hail, etc.) and is made up of two components, *rainouts* which describes incorporation within the cloud layer, and *washout*, describing scavenging by falling raindrops. The overall efficiency is described by the *scavenging ratio, W,* often rather misleadingly referred to as the Washout Factor.

$$W = \frac{\text{Concentration in rainwater (mg kg}^{-1}\text{)}}{\text{Concentration in air (mg kg}^{-1}\text{)}}$$

Typical values of scavenging ratio are given in Table 3.5. A large value implies efficient scavenging, perhaps resulting from extensive vertical mixing into the cloud layer, where scavenging is most efficient. A related deposition process termed 'occult' deposition occurs when pollutants are deposited by fogwater deposition on surfaces. Pollutant concentrations in fogwater are typically much greater than in rainwater, hence the process may be significant despite the modest volumes of water deposited.

Another sink process involves chemical conversion of one pollutant to another (termed dry transformations). Thus atmospheric oxidation to sulphuric acid is a sink for sulphur dioxide. For many pollutants, a major sink is atmospheric reaction with the hydroxyl radical (OH). Since pollutants are continually emitted into, and removed from the atmosphere, they have an associated atmospheric lifetime or residence time.

Table 3.5: *Typical scavenging ratios.*

Species	W
Cl^-	0600
SO_4^{2-}	0700
Na	0560
K	0620
Mg	0850
Ca	1890
Cd	0390
Pb	0320
Zn	0870

EFFECTS OF AIR POLLUTION

Substantial evidence has been accumulated to prove that air pollution affects the atmospheric properties, damages vegetation, and health of human beings, animals, soils and deteriorates materials, affects climate, reduces visibility and solar radiation, impairs production processes, contributes to safety hazards, and generally interferes with the enjoyment of life and property. Although some of these effects are specific and measurable, such as damages to vegetation and material and reduced visibility, most are difficult to measure, such as health effects on human beings and animals and interference with comfortable living. Each of the effects listed above has been the subject of considerable attention, and a number of comprehensive reviews of the effects of air pollution have been written. In this section we shall present a brief summary of some of the most important established effects of air pollution.

EFFECTS OF AIR POLLUTION ON ATMOSPHERIC PROPERTIES

Air pollutants affect atmospheric properties in the following ways:

- Visibility reduction
- Fog formation and precipitation
- Solar radiation reduction
- Temperature and wind distribution alteration

These effects are primarily associated with the urban atmosphere. In addition, there has been much awareness currently of the possible effects of air pollutants, mainly carbon dioxide and particles, and on the atmosphere as a whole.

In addition to reducing visibility, air pollution affects urban climates with respect to increased fog formation and reduced solar radiation. The frequency of fog formation has been observed to be higher in cities than in the country in spite of the fact that air temperatures tend to be higher and relative humidities tend to be lower in cities as opposed to the country. The explanation for this observations lies in the mechanism of fog formation.

Scattering and absorption of both solar and infrared radiation, as well as emission of radiation, occur within the polluted layer. The net effect of these radiative processes during the night is a marked cooling of the pointed layer.

Studies carried out in London, for example, have shown that the average duration of bright sunshine in central London (in hours per day) is discernibly less than in the surrounding countryside (Georgii, 1969). In general, the decrease in direct solar radiation due to a polluted layer amounts to 10 to 20 per cent.

Effects of air pollution on materials are also considerable. Air pollutants can affect materials by soiling or chemical deterioration. High smoke and particulate levels are associated with soiling of clothing and structures, and acid or alkaline particles, especially those containing sulphur, corrode materials, such as paint, masonry, electrical contacts, and textiles. Ozone is particularly effective in deteriorating rubber (Jaffe, 1967).

EFFECTS OF AIR POLLUTION ON VEGETATION

Pollutants, which are known as phytotoxicants (substances harmful to vegetation), are sulphur dioxide, peroxyacetyl nitrate (an oxidation product in photochemical smog) and ethylene. Of somewhat lesser severity are chlorine, hydrogen chloride, ammonia, and mercury. In general, the gaseous pollutants enter the plant through the stomata in the course of normal respiration of the plant. Once lodged in the leaf of the plant, pollutants destroy chlorophyll and disrupt photosynthesis. Damage caused can range from a reduction in growth rate to complete death of the plant. Symptoms of damage are usually manifested in the leaf, and the particular symptoms often provide the evidence for the responsible pollutant (Fig. 3.8). Table 3.6 summarizes the symptoms characteristic of plant damage by several pollutants.

Figure 3.8 *Effects of air pollution: degree of injury on Ribes* rubrum leaves *in various stages of development after exposure to acute SO_2 concentration.*

Table 3.6 *Summary of Symptoms and Injury Thresholds for Air Pollution Damage to Vegetation*

Pollutants	**Symptom**	**ppm**	**Sustained exposure time**
Ozone (O_3)	Fleck, bleaching, bleached spotting, growth suppression. Tips of conifer needles become brown and necrotic.	0.03	4 hr
SO_2	Bleached spots, bleached areas between veins, chlorosis, growth suppression, reduction in yield.	0.03	8 hr
Peroxyacetyl Nitrate (PAN)	Glazing, silvering or bronzing on lower surface of leaves.	0.01	6 hr
HF	Tip and margin bum, chlorosis, dwarfing leaf abscission, lower yield.	0.0001	5 weeks
Cl_2	Bleaching between veins, tip and leaf abscission.	0.01	2 hr
Ethylene (C_2H_4)	Withering, leaf abnormalities, flower dropping, and failure of flower to open.	0.05	6 hr

EFFECTS OF AIR POLLUTANTS ON HUMAN HEALTH

We now come to the most controversial and probably the most important effect of air pollution, that is on human health. First we consider the mechanisms by which pollutants can affect the human body. We would then discuss the type of evidence available on the effects of long-term exposure to pollutant levels characteristic of urban areas.

Pollutants enter the body through the respiratory system, which can be divided into the upper respiratory system, consisting of the nasal cavity and the trachea, and the lower respiratory system, consisting of the bronchial tubes and the lungs. At the entrance to the lungs, the trachea divides into two bronchial trees (Fig. 3.9) which consist of a series of branches of successively smaller diameter. The entire bronchial tree consists of over 20 generations of bifurcations, ending in bronchioles of diameters of about 0.05 cm. At the end of the bronchioles are large collections of tiny sacs called alveoli. It is across the alveolar membranes that oxygen diffuses in the opposite direction. Although an individual alveolus has a diameter of only about 0.02 cm, there are several hundred million alveoli in the entire lung, providing a total surface area of roughly 50 m^2 for gas transport.

The respiratory system has several levels of defense against invasion by foreign material. Large particles are filtered from the airstream by hair in the nasal passage and are trapped by the mucus layer lining the nasal cavity and the trachea. These large particles are unable to negotiate the sharp bends in the nasal passage, and because of their inertia, impinge on the wall of the cavity as the air rushes down towards the lung. In addition, particles may also be scavenged by fine hair-like cilia which line the walls of the entire respiratory system. These cilia continually move mucus and trapped material to the throat where they are removed by swallowing. Most particles of sizes exceeding 5 mm are effectively removed in the upper respiratory system.

Particles of radii less than a few micrometres generally pass through the upper respiratory system, escaping entrapment. Some of the particles larger than these (about 1 μm in size) are deposited on the bronchial walls immediately behind bifurcations in the bronchial tree. The mechanism for this deposition is believed to be inertial impaction which results from the swirling air motions caused by the bifurcation. Very small particles (radii < 0.1 μm) are strongly influenced by Brownian motion (rapid, irregular movement due to collisions of the particle with air molecules). As a result, these particles have a high probability

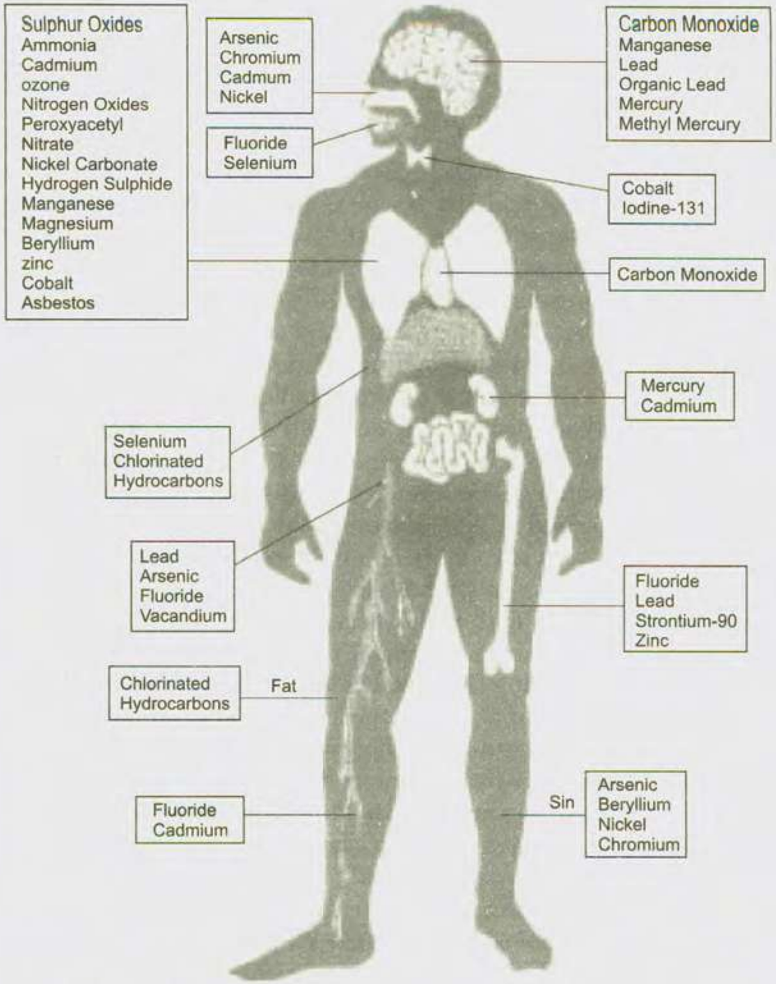


Figure 3.9: *The side of effects of some major pollutants in human beings*

of striking the bronchial walls somewhere in the bronchial tree. There is effectively a 'window' in the size range 0.1 to 1 μm, where the particles are too large to be influenced by Brownian motion, but are too small to be trapped in the upper portion of the lung. Particles in this size range are able to penetrate deep into the lung. Table 3.7 prepared by WHO summarizes some observed relations between pollutant levels and physiological

Table 3.7: *Effects and Guidelines for Major Air Pollutants*

Pollutant	**WHO guidelines (micrograms per cubic metre of air) (mg/m^3)**		**Effects**
	Annual	**Percentile mean**	
Sulphur dioxide (SO_2)	40–60	100–150	Exacerbation of respiratory illness from short-term exposures.
Suspended particulate			Same as for SO_2 combined exposure to SO_2 and SPM may have pulmonary effects
Black smoke	40–60	100–150	
Total suspended particulates	60–90	150–230	
Lead	0.5–1	0	
Nitrogen dioxide			Blood enzyme changes cause anaemia, Hyperactivity and neurobehavioural effects
1 hour	400	–	
24 hour	0	150	
Carbon monoxide (mg/m^3)			
15 minutes	100	–	Effects on lung function in asthmatics from short-term exposures
1 hour	30	–	
30 minutes	–	60	
8 hour	–	10	
Carboxyhemoglobin		23.53%	Reduces oxygen-carrying capacity of the blood

WHO: World Health Organization.

responses. In many cases, we can account for the responses by considering the mechanisms of irritation of individual pollutants.

For gases, the solubility governs what proportion is absorbed in the upper airway and what proportion reaches the terminal air sacs of the lungs. For example, SO_2 is quite soluble and consequently, is absorbed early in the airway, leading to airway resistance (swelling) and stimulated mucus secretion (Fig. 3.9). On the other hand, CO, NO_2, and O_3 are relatively insoluble and are able to penetrate deep into the lung to the air sacs. Nitrogen dioxide and ozone cause pulmonary edema (swelling), which inhibits gas transfer to the blood. Carbon monoxide is transported from the air sacs to the blood and combines with haemoglobin as oxygen does.

It is important to note that more than one pollutant may induce the same effect. For example, both sulphur dioxide and formaldehyde produce irritation and increased airway resistance in the upper respiratory tract, and both CO and NO_2 interfere with oxygen transport by hemoglobin. Several pollutants are usually present at the same time, and as a result, observed effects may actually be attributable to the combined action of more than one pollutant. A good example of this is the case of SO_2 and particulate matter. Effects on health become far more serious when both are present than if either occurs separately. A possible explanation for this effect is that SO_2 becomes absorbed on the surface of very small particles and is carried by the particles deep into the lung.

CASE STUDIES OF AIR POLLLUTION

London Smog

The Mediterranean sea has a coastline of 48,000 km where about 100 million people live. It is surrounded on all sides by Europe with a Gibraltar strait connecting to the Atlantic. Here the famous luxury tourist hotel and numerous industries are located. The industries dump their wastes into the Mediterranean sea, which also receives sewage from the European countries. As a result, the sea is heavily polluted with high levels of lead, chromium, mercury, etc. The seashore emits offensive odour due to pollution, which forces closure of the tourist hotels for some six months every year. The sea became so heavily polluted since 1950 that it was declared a dead sea, unable to support any aquatic life (fish, plants, etc.).

Nuclear Explosions

The two atom bombs were dropped by USA during World War II (August 6, 9, 1945) on Hiroshima and Nagasaki in Japan. These instantly killed about 6 lakhs people, destroyed the two cities and unleashed radioactive fallout which has caused generations to suffer from various diseases including genetic disorder. Radioactive radiation continues to damage plants, soil and biosphere in the region.

Bhopal Disaster (December 3, 1984)

This is the worst environmental disaster in human history. A pesticide factory, Union Carbide Corporation, leaked large volumes of methyl isocyanate (raw material for production of the pesticide, Carbaryl) into the atmosphere of Bhopal on December 3, 1984 at around midnight. Very soon the city was transformed into a gas chamber. Within a week 10,000 people died, 1000 people turned blind and lakhs of people continue to suffer from various diseases. This was mass murder in recent history and the victims/survivors are yet to receive their compensation from the Union Carbide Corporation or the government. It was the end result of negligence on the parts of the Central and State Governments and factory manager on one hand and lack of awareness among the public and hospital doctors on the other hand.

Chernobyl Disaster (1986)

The worst nuclear reactor accident occurred at Chernobyl, USSR (now CIS), on 28th April, 1986. The reactor exploded as a result of uncontrolled nuclear reactions—radioactive fuel and debris shot up into air like a volcanic explosion and spread out in the surrounding areas. The accident killed at least 2000 people and damaged soil, water and vegetation in an area of 60 sq. km around Chernobyl. Several generations in the region suffer from radiation-induced diseases including cancer.

Gulf War Hazards

The Gulf War was of six weeks duration (1991) fought between Iraq and USA-led multinational coalition forces under the banner of the United Nations. The issue was annexation of a neighbouring state, Kuwait by Iraq in utter violation of international law and order. The war was fought for liberation of Kuwait and provides the latest example of how war destroyed the environment for several years.

The Gulf War destroyed Iraq and Kuwait. Cities and roads can be rebuilt but environment cannot be rebuilt. It will take several decades for the environment to be recovered.

About one lakh one-ton bombs were dropped on Iraq, raising clouds of dust and black smoke. About 700 oil wells were set ablaze in Kuwait for over 10 months, whereby black smoke and soot were shot up at high altitudes of the atmosphere. They moved with winds encircling the earth, warmed up the upper atmosphere causing temperature inversion (warm air over cool air mass). They disrupted monsoon circulation in the region and caused acid rain and crop damage in South-East Asia. The global temperature dropped by about 0.5°C. Besides these, a total of 200 million gallons of oil was dumped into the Persian Gulf, which destroyed the marine ecosystem.

At the end of the war, the world witnessed a scene of "hell on Earth"-chaos of oil fire, smoke, oil spill and a landscape of mines. It was the toughest challenge to handle such an environmental disaster. But this almost impossible task was handled by a number of United Nations Agencies and several national and international agencies with the co-ordination of UNEP (United Nations Environment Programme) working hard for about one year.

Acid Rain and Control Strategies

'Acid rain' is a broad term used to describe several ways by which acids fall out of the atmosphere. The term 'acid rain' was first coined in 1872, after a link was made between sulphur dioxide emissions from the burning of coal in Manchester to the acidification of nearby rainfall. A more precise term is "acid deposition", which has two parts: wet and dry. Snow, sleet, and mist are collectively known as "wet deposition"; and gases, dusts, and smog collectively make "dry deposition".

Prevailing winds blow the compounds that cause both wet and dry acid deposition across state and national borders, and sometimes over hundreds of miles. Scientists have confirmed that sulphur dioxide (SO_2) and nitrogen oxides (NOx) are the primary causes of acid rain. In the United State of America, about 2/3 of all SO_2 and 1/4 of all NOx comes from electric power generation that relies on burning fossil fuels like coal. Acid rain occurs when these gases react in the atmosphere with water, oxygen, and other chemicals to form various acidic compounds. Sunlight increases the rate of most of these reactions. The result is a mild solution of sulphuric acid and nitric acid. Normal rainfall is slightly acidic (pH 5.6). This is because carbon dioxide dissolves in water to form carbonic acid. Rainfall with a pH of less than 5.6 is called acid rain. The pH of acid rain in Western Europe can be between 4.0 and 4.5.

Chemistry

Dry deposition affects the environment directly. It combines with fog and dust to produce smog. It damages buildings, historical and modern, eroding away limestone and marble, and penetrating concrete structures to corrode the steel reinforcement within. Deposition on farmland sand forestry affects plant growth and reduces crop yields. Since sulphur and nitrogen are both plant nutrients, their deposition can affect the competitive abilities of different plant species: plants with a high nutrient demand thrive at the cost of those with a lower nutrient demand.

Wet deposition shares all same direct effects of dry deposition. In addition, it has a particularly potent acidifying effect on lakes, rivers, and streams. Direct deposition in the water is compounded by the inflow of groundwater from nearby acidified soils. The effects on aquatic life are two-fold:

1. Acidification is further intensified; the more the pH decreases, the more the damage. Below 4.5, most aquatic life is affected.
2. Toxic metals, such as aluminium, leached by the acid in the soil, are introduced to the water. Aluminium has a direct effect on the respiratory systems of fish, causing their gills to clog up. The presence of toxic metals in water supplies presents a health problem to all animal life, including humans.

The severity of the effects of wet deposition depends on a number of area-specific factors:

- Soil type—the more naturally acidic the soil is, the more at risk the ecosystem it supports is from the effects of acid rain.
- Soil cover—the thinner the soil layer, the more readily it is affected by acidification.
- Mix of plant species—acidification tends to be exacerbated in areas with conifer plantations. Conifers are particularly effective scavengers of pollutants. The unfortunate effect of this is that more acid pollution can pass into the soil beneath them. The acid then leaches out toxic metals, which pass into groundwater.

- Rainfall levels—the more acid rain the greater the damage.
- Altitude—upland areas are more affected than lowland areas: (1) through higher rainfall, and (2) through increased contact with acid clouds and mists.

Effect on Automotive Coatings

Damage to automotive paints and other coatings typically occurs on horizontal surfaces and appears as irregularly shaped, permanently etched areas. The damage can best be detected under fluorescent lamps, can be most easily observed on dark coloured vehicles, and appears to occur after evaporation of a moisture droplet. In addition, some evidence suggests that damage occurs most frequently on freshly painted vehicles. Usually the damage is permanent; once it has occurred, the only solution is to repaint.

Effect on Lakes and Streams

Many lakes and streams examined in a National Surface Water Survey (NSWS), United State of America, suffer from chronic acidity—a condition in which water has a constant low pH level. The survey investigated the effects of acidic deposition in over 1,000 lakes larger than 10 acres and in thousands of miles of streams believed to be sensitive to acidification. Of the lakes and streams surveyed, acid rain caused acidity in 75 per cent of the acidic lakes and about 50 per cent of the acidic streams.

Effect on Fish and Other Qquatic Organisms

Acid rain causes a cascade of effects that harm or kill individual fish, reduce fish population, completely eliminate fish species from a water body, and decrease biodiversity. As acid rain flows through soils in a watershed, aluminum is released from soils into the lakes and streams located in that watershed. So, as pH in a lake or stream decreases, both low pH and increased aluminum levels are directly toxic to fish.

Effect on Ecosystems

The plants and animals living within an ecosystem are highly interdependent. For example, frogs may tolerate relatively high levels of acidity, but if they eat insects like the mayfly, they may be affected because part of their food supply may disappear. Because of the connections between the many fish, plants, and other organisms living in an aquatic ecosystem, changes in pH or aluminum levels affect biodiversity as well. Thus, as lakes and streams become more acidic, the numbers and types of fish and other aquatic plants and animals that live in these waters decrease.

Effect on Forests

Acid rain is known to cause slower growth, injury, or death of forests. Acid rain has been implicated in forest and soil degradation in many areas of the world. In most cases, in fact, the impacts of acid rain on trees occur due to the combined effects of acid rain and environmental stressors such as air pollutants, insects, disease, drought, or very cold weather. After many years of collecting information on the chemistry and biology of forests, researchers are beginning to understand how acid rain works on the forest soil, trees, other plants and soil organisms.

Acid rain does not usually kill trees directly. Instead, it is more likely to weaken trees by damaging their leaves, limiting the nutrients available to them, or exposing them to toxic substances slowly released from the soil. Quite often, injury or death of trees is a result of these effects of acid rain in combination with one or more additional threats. Acid rain causes the release of substances that are toxic to trees and plants, such as aluminum, into the soil. Scientists believe that this combination of loss of soil nutrients and increase of toxic aluminum may be one way in which acid rain harms trees. Such substances also wash away in the runoff and are carried into streams, rivers, and lakes. More of these substances are released from the soil when the rainfall is more acidic.

Trees can be damaged by acid rain even if the soil is well buffered. Forests in high mountain regions are often exposed to greater amounts of acid than other forests because they tend to be surrounded by acidic clouds and fog that are more acidic than rainfall. Scientists believe that when leaves are frequently exposed to this acid fog, essential nutrients in their leaves and needles are stripped away. This loss of nutrients in their foliage makes trees more susceptible to damage by other environmental factors, particularly cold winter weather.

Effect on Human Health

Recent studies have shown a strong link between high levels of SO_2 in the air and increased occurrence of heart and breathing problems. These pollutants can be deposited through rain, snow, fog, dew, or sleet. Large quantities can also be deposited in a dry form through dust. These pollutants may be carried hundreds of kilometres before being deposited on the Earth. So, pollution that is emitted in one country can do most of its damage in another country.

Prevention of Acid Rain

To solve the acid rain problem, people need to understand how acid rain causes damage to the environment. They also need to understand what changes could be made to the air pollution sources that cause the problem. The answers to these questions help authorities make better decisions about how to control air pollution and therefore how to reduce, or even eliminate, acid rain. Since there are many solutions to the acid rain problem, authorities have a choice between options or combination of options. The next section describes some of the steps that can be taken to reduce, or even eliminate, the acid deposition problem.

STUDY QUESTIONS

1. Describe briefly the origin of atmosphere.
2. Give a detailed account of vertical structure of atmosphere.
3. Describe the process of photochemical oxidation in atmosphere.
4. Classify different air pollutants and discuss their properties.
5. Discuss in detail the effects of air pollution on human health.
6. Give an account of methods used for sampling of gaseous pollutants.
7. Write an assay on acid rain and its control.
8. Write short notes on the following:
    - (a) Photochemical smog
    - (b) Effect of air pollution on vegetation
    - (c) Effect of air pollution on atmospheric properties
    - (d) Analysis of sulpher dioxide
    - (e) Spectrophotometeric determination of H_2S

(f) Analysis of ozone
(g) London Smog
(h) Bhopal gas tragedy

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4

Hydrosphere, Water Pollution and Waste Water Treatment

INTRODUCTION

Our world is awash with water. No other planet, as far as we know, has anything like a sea. Seven-tenths of earth is covered by great oceans. The water being held to the earth may occur as a gas, a liquid or a solid depending upon the temperature. As a liquid, it forms hydrosphere, which covers approximately three-fourths of the earth's surface. It tends to flow downward into the lowest depressions on the surface of earth, forming streams, lakes and rivers.

HYDROLOGIC CYCLE

Interchange of water between earth's surface and atmosphere is governed by a cycle known as hydrologic cycle (Fig. 4.1). Significant amounts of water are incorporated by ecosystems in protoplasmic synthesis and there is a substantial return to the atmosphere by transpiration. The relative and absolute amounts of precipitation and evaporation determine the structure and function of ecosystems. According to Hutchinson (1957), world precipitation amounts to about 4.46×10^{20} g annually. Of this about 0.99×10^{20} g falls on land and 3.47×10^{20} g on ocean surfaces. Water content of various parts of the earth is exhibited in Table 4.1.

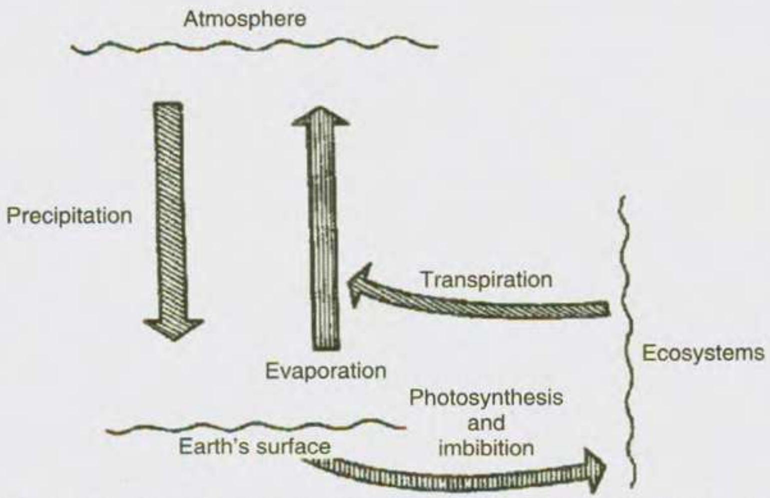

Figure 4.1: *The general pattern of the hydrologic cycle. Note that the significance of ecosystem in the movement of water is largely by way of transpiration; some water is lost from ecosystems as respiration and perspiration and becomes a component of surface evaporation*

Table 4.1: *Water content of the various parts of the Earth (Hutchinson, 1957)*

	Content (g)
Primary lithosphere	$250{,}000 \times 10^{20}$
Ocean	$13{,}800 \times 10^{20}$
Sedimentary rocks	$2{,}100 \times 10^{20}$
Polar caps & other ice	167×10^{20}
Circulating ground water	2.5×10^{20}
Inland waters	0.25×10^{20}
Atmospheric water vapour	0.13×10^{20}
Total:	$\mathbf{266{,}069.88 \times 10^{20}}$

Control of Hydrologic Cycle

Hydrologic cycle encompasses the movement of water from the ocean to the atmosphere and back to the ocean again by way of evaporation, runoff in streams and rivers and groundwater flow. Only a small amount of water in the ocean is active in the hydrologic cycle at any one time, and yet this small amount of water is very important in the movement and sorting of chemical elements (biogeochemical cycles), shaping the landscapes, weathering the rocks, transporting and depositing sediments and providing us with water resources.

The hydrologic cycle is important for limnology. It forms freshwater bodies like ponds and lakes. The South face of Himalayas receives 1200 cm of rain annually. However, the entire fresh water on land surface of the earth is 0.25×10^{20} gm. Himalayas is the main rain bringing barrier in North India and the Eastern and Western Ghats of South India. In the absence of barriers, there is little precipitation, viz. deserts of Gobi, Sahara and Rajasthan where annual rainfall is less than 25 cm.

FRESH WATER ENVIRONMENT

Fresh water is a home for numerous organisms. As a habitat, we can divide it into two groups:

(i) *Standing* or *lentic water:* (Lenis = calm) e.g., lake, pond, swamp or bog.

(ii) *Running* or *lotic water:* (Lotus = washed) e.g., spring, stream and river.

Furthermore, aquatic habitat can be divided into subhabitats:

- ***Littoral zone:*** This is the shallow water region where light can reach upto the bottom. It is chiefly occupied by rooted plants.
- ***Limnetic zone:*** This is the open water zone upto the depth of effective light penetration. The community of this zone comprises plankton, nekton and sometimes neustons. Total illuminated stratum including littoral and limnetic zones is called euphotic zone.

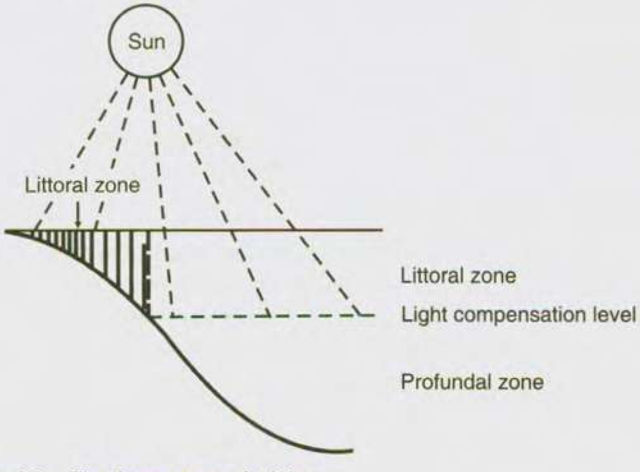

Figure 4.2: *The three zones of a lake*

- ***Profundal zone:*** The bottom and deep water area where light does not penetrate is called *profundal zone*. This zone is often absent in ponds (Fig. 4.2).

Organisms of fresh water may be conveniently classified as producers, consumers and decomposers. However, those living in the bottom sediments are called *benthos*, those living on projected surfaces such as stems and leaves are called *periphyton*; and those flying freely with the water current are called *plankton*. There are other smaller organisms that can swim and navigate at will, known as *nekton*. Organisms resting or swimming on the surface are called *neustons*.

Physico-chemical Nature of Fresh Water

The quality of water determines the distribution and abundance of aquatic flora and fauna. The following properties are important from ecological point of view:

Temperature: There has been diurnal and seasonal changes in the temperature of water in ponds, lakes, etc. In shallow water habitats difference between day and night temperature has been recorded. However, flowing lotic waters of streams and rivers lack fluctuations in temperature.

Phenomenon of thermal stratification has also been reported in the lakes and ponds of tropical countries. Moreover, temperature has been used to determine the type of lake:

(a) Tropical lakes, where the surface temperature is always above 4°C.
(b) Temperate lakes, where the temperature varies above and below 4°C.
(c) Polar lakes, where surface temperature never goes above 4°C. The extremes of lower and higher temperature have lethal effects on aquatic organisms. Temperature regulates different activities like breeding, hibernation and migration in fresh water biota.

Pressure density and buoyancy: The pressure imposed on aquatic organisms is the weight of the column of water above it plus the weight of atmosphere.

The density of water is inversely proportional to temperature, as we see that ice always forms at the surface than at the bottom of a lake. Dissolved salts increase the density of water. Therefore, the density of inland waters is less than the oceanic water.

Higher percentage of salts in fresh water leads to *hypersalinity*—a condition lethal to many aquatic organisms.

Buoyancy of an object is equal to the weight of water it replaces. It is influenced by all those factors that affect density. Most of the aquatic organisms have adaptations to decrease the specific gravity of body by swimming, thus taking large amounts of water and storing air in the body. When these mechanisms cease to work, the animal dies.

Light: Light influences fresh water ecosystems by interfering with their productivity. A shallow lake receives light upto its bottom surface resulting into abundant growth of vegetation. These plants provide food to consumers in the food chain and a balance in the ecosystem is maintained. The running water contains less producers because of the water currents that pass the light away. Light controls the orientation, growth and position of several aquatic organisms.

Oxygen: Oxygen remains dissolved in fresh water. It reaches the water either by direct diffusion or by wave action and water circulation. Lotic water of streams and rivers hence contains high percentage of oxygen. Phytoplankton and aquatic plants supply water with oxygen as a product of photosynthesis. Diurnal variations in oxygen have been observed in tropical ponds. Oxygen is primarily utilized in respiration by organisms as well as in the decomposition of dead organisms. In stagnant pools, with a lot of decaying vegetation, oxygen often reaches a stage of complete depletion. However, certain fresh water inhabitants such as anaerobic bacteria do not require oxygen.

Carbon dioxide: Carbon dioxide plays an important role in aquatic ecosystems. Aquatic vegetation and phytoplankton require carbon dioxide for photosynthetic activity. It is the end product of respiration and decomposition, and it also diffuses directly from the atmosphere. It is present in fresh water as carbonates and bicarbonates of calcium, magnesium and other minerals. Higher saturation levels of oxygen and CO_2 exert toxic effects on aquatic biota.

Other gases: Water systems that receive sewage effluents and other pollutants show an abundance of H_2S as a decomposition product. Methane and carbon monoxide are other toxic gases, which are the products of decomposition. Nitrogen, hydrogen, sulphur dioxide and ammonia may be found dissolved in fresh water.

Dissolved salts and salinity: Fresh water contains many solutes, which reach the water by erosion and as faeces of aquatic animals. Compounds like nitrogen, phosphorus and silicon are most important substances found dissolved in fresh water. Nitrates, nitrites and ammonia salts are essentially the food for aquatic vegetation. Many other elements like phosphorus, calcium, magnesium, manganese, iron, sodium, potassium, sulphur and zinc dissolved in water also influence the fauna.

Salinity of the fresh water directly affects osmoregulation in fresh water animals.

pH: Hydrogen ion concentration of the fresh water is an important limiting factor. pH of the surface water and deeper waters exhibits marked differences. Different animals show affinity towards specific pH conditions.

LAKES

Lakes are naturally formed from hollows or depressions on the surface of the earth and get filled with water. Fresh water bodies where the limnetic and profundal zones are relatively large are known as lakes. Lake has been defined by Ford (1892) as a body of standing water occupying a basin and lacking continuity with the sea. Muttouskii (1918) refers to lakes as the bodies of standing water which are of considerable expanse and deep enough to stratify thermally. Welch (1952) regarded all large bodies of standing water as lakes.

Lakes can be formed through:

(a) glacial action;
(b) land slides;
(c) dissolution of soluble rocks of the substratum;
(d) crustal movements of the earth;
(e) volcanic action;
(f) wind action; or
(g) river meanderings.

RESERVOIRS

Damming of streams has been in vogue since time immemorial. Imitating beavers, prehistoric man dammed streams by putting sticks or bamboos across a stream to trap fish. Familiarity with such practices led to the formation of impoundments and diversion of waters for irrigation after the advent of agriculture.

With the passage of time, the scope of dams has expanded and at present dams are constructed for multiple objectives, namely, water storage for public supplies, irrigation reserves, hydroelectric power, flood control, navigation, recreation, development of fisheries and sport fishing.

Dubey has brought out a booklet titled *Development of Fisheries in Reservoirs* under the auspices of the Madhya Pradesh Fisheries Corporation. Quoting National Commission on Agriculture (NCA), Dubey has stated that 3.0 million ha of reservoirs exist in India and the reservoir area would spread to 6.0 million ha by the turn of the century. Quoting Indian Institute of management, Ahmedabad (IIMA, 1983), Dubey states that India has 975 reservoirs of which 550 are major ones of the latter, 5 per cent are very large (above 10,000 ha), 3 per cent large (5,000–10,000 ha), 26 per cent medium (1,000–5,000 ha) and the rest 66% are small (50–1,000 ha). Hirakud in Orissa is at present the country's largest reservoir followed by Gandhisagar in Madhya Pradesh (66,000 ha) and Rihand in Uttar Pradesh (46,000 ha).

MARINE ENVIRONMENT

The seas first formed when the earth began to cool soon after its birth and hot water vapour condensed on its surface. They were further fed by water gushing through volcanic vents from the interior of the earth. The water of these young sea was not pure, but contained significant quantities of chlorine, bromine, iodine, boron and nitrogen as well as traces of many rare elements. Since then, other ingredients have been added. As continental rocks weather and erode, they produce salts which are carried in the form of solution down to the sea by the rivers. So, over millennia, the sea has been getting saltier and saltier.

The major oceans (Atlantic, Pacific, Indian, Arctic and Antarctic) and their extensions cover approximately 70 per cent of the earth's surface. Physical factors like waves, tides, currents, salinities, temperatures, pressures and light dominate life in the ocean and determine the make-up of biological communities. These communities have considerable effect on biomass, which is far greater than the combined biomass of land and fresh water. Sea influences the climate of the land areas, but is dominated by waves and tides produced by the pull of the sun and the moon.

The sea water is salty with an average salt concentration of 3.5 per cent, usually written as 35 per cent, whereas fresh water has a salinity of less than 0.5 per cent. In addition to salt, marine water contains the following radicals as well:

Positive ions (%)			**Negative ions (%)**		
Sodium	=	10.7	Chloride	=	19.3
Magnesium	=	1.3	Sulphate	=	2.7
Calcium	=	0.4	Biocarbonate	=	0.1
Potassium	=	0.4	Carbonate	=	0.007
Bromide	=	0.07			

Oceanography

Oceans are known to be our last frontiers. They are the storehouse of food, minerals, oil and gas energy. Study of oceans is called *oceanography*. In India, oceanography is relatively a young discipline of science. A systematic study of the Indian ocean started with India's participation in the International Ocean Expedition (1960–1965). In 1966, the National Institute of Oceanography came into existence and started multidisciplinary studies of the ocean. The declaration of 200 mile Exclusive Economic Zone (EEZ) added new dimensions to the development programme of the oceans. Government of India, with the above aspects in view, created a new Department of Ocean Development through President's Notification No. CD 80081 dated 24th July 1981.

The Department of Ocean Development covers the following areas:

(i) Living resources
(ii) Non-living resources
(iii) Ship management
(iv) Manpower planning
(v) International collaboration and antarctic programmes
(vi) Data collection and dissemination
(vii) Legal regime

Physico-chemical Aspects of Marine Environment

Light, temperature, pressure, currents, tides and salinity are the physico-chemical characters that need further elaboration with reference to sea. However, they vary in different zones of the sea as described below.

Zonation in the sea: The ocean itself can be divided into two main divisions—the pelagic or whole body of water, and the benthic or bottom of the sea. The pelagic region has two provinces—the neritic (near shore) zone and oceanic zone.

The neritic province is further divided into three zones, viz. the *littoral* or *intertidal* zone that lies between high and low tides, the *sublittoral* or subtidal zone that extends from the low tidal mark to the edge of continental shelf and *lower neritic zone* that meets at oceanic region.

The oceanic province has also been further divided into *euphotic* or producing zone where photosynthesis takes place, and *bathyal* zone, which is the abyssal zone that begins at the depth of about 2000 m. Abyssal ocean is the world's largest ecological unit. These primary zones are based on physical factors as described here.

(i) **Light**: Euphotic zone of the ocean receives sufficient light, and as such it is called the producing zone. Other zones do not receive effective light but inhabit different animal communities. Deep sea fauna generally lack functional eyes, whereas light determines diurnal migrations and colour of marine animals.

(ii) **Temperature:** The temperature of the sea varies at different geographical position and in different zones. Arctic waters are much colder (27°F) than the tropical waters (81°F). Seasonal and daily temperature changes are larger in coastal waters than the open sea. In general, sea water is never more than 2° to 3°F below the freezing point of fresh water or higher than 81°F. Sea water becomes denser as it gets colder.

(iii) **Pressure:** Pressure in the ocean varies from 1 atm at the surface to 1,000 atm at the greatest depth. Pressure determines the distribution of animals. However, certain animals like sperm whales and seals can withstand a large range of pressure.

(iv) **Salinity:** The absence of many animal and plant species from the sea has been related to their inability to tolerate high salt contents of sea water. The salinity of marine water fluctuates from place to place caused by the dissolved salts of chlorides of sodium, potassium, calcium and magnesium and also the sulphates of calcium and magnesium.

(v) **Currents and tides:** Sea water is never static and waves, currents and tides are the regular features of sea water. These currents cause an interchange between surface and deep sea water. In this way the productivity of marine communities is controlled. Tides are especially important in shoreward zones where marine life is both varied and dense. Since tides have a periodicity of about $12^1/_2$ hours, high tides occur in most localities twice a day. After every two weeks when the sun and the moon together exert the forces of gravity, the amplitude of tides is increased, whereas in the middle of fortnightly periods, the range between low and high tide is small. The tidal range varies from less than 1 foot in the open sea to 50 feet in certain enclosed bays. Tide patterns vary in different parts of the world.

WATER POLLUTION

Water is a vital natural resource which is essential for our survival. Its many uses include drinking and other domestic uses, industrial cooling, power generation, agriculture (irrigation), transportation and waste disposal. In the chemical process industry, water is used as a reaction medium, a solvent, a scrubbing medium, and a heat transfer agent. As a source of life for man, plants and other forms of life it cannot be replaced.

Dozens of times a day those of us who live in the industrialized nations of the world enjoy a blessing denied to 75 per cent of the world population, i.e., abundant supplies of clean water. Water is most essential for life on earth. No known organism can live without it. For centuries, water has been used as a dumping ground for human sewage and industrial wastes. Added to them are the materials leached out and transported from land by water percolating through the soil and running off its surface to aquatic ecosystems. Thus, the term 'water pollution' refers to *Water contamination by a variety of chemical substances or eutrophication caused by several nutrients and fertilizers* (Southwick, 1976). US Department of Health Education and Welfare defines water pollution as *the adding to water of any substance, or the changing of water's physical and chemical characteristics in any way which interferes with its use of legitimate purposes.*

Origin of Wastewater

Wastewaters can be classified by their origin as domestic wastewater and industrial wastewater. Any combination of wastewater that is collected in municipal sewers is termed as municipal sewage. Domestic wastewater is that which is discharged from residential and commercial establishments, whereas industrial wastewater is that which is discharged from manufacturing plants. The pollutants in domestic wastewater arise from residential and commercial cleaning operations, laundry, food preparation, body cleaning functions, and body excretions. The composition of domestic wastewater is relatively constant.

Industrial wastewater is formed at industrial plants where water is used for various processes, and also for washing and rinsing of equipment, rooms, etc. These operations result in the pollution of the products, and byproducts are discharged, either deliberately or unintentionally into them.

Normally, wastewaters are conducted to treatment plants for removing undesirable components, which include both organic and inorganic matter as well as soluble and insoluble material. These pollutants, if discharged directly or with improper treatment, can interfere with the self-cleaning mechanisms of water bodies. The capacity for self-cleaning is due to the presence of relatively small numbers of different types of microorganisms in the water bodies. These microorganisms use as food much of the organic pollutants and break them down into simple compounds such as CO_2 or methane, and the microorganisms produce new cells also. But often, either a pollutant does not degrade naturally or the sheer volume of the pollutant discharged is sufficient to overwhelm the self-cleaning process. Also, the microbial population can be destroyed by toxic wastes build-up and reach levels that would be high enough to prevent re-establishment of a microbial population. The water quality thus becomes permanently degraded.

Various constituents of wastewater are potentially harmful to the environment and to human health. In the environment, the pollutants may cause destruction of animal and plant life, and aesthetic nuisance. Drinking water sources are often threatened by increasing concentration of pathogenic organisms as well as by many of the new toxic chemicals disposed of by industry and agriculture. Thus, the treatment of these wastes is of paramount importance.

The major sources of water contamination have been domestic, industrial, agricultural waste products, solid wastes, heat and radioactive materials.

Domestic Water Pollution

It is mainly caused by sewage. Sewage is defined as the water-borne waste derived from home, animal or food processing plants and includes human excreta, soaps, detergents, paper and cloth. They are the largest group of water pollutants. Water pollution is caused by uncontrolled dumping of wastes from villages, towns and cities into ponds, streams, lakes and rivers. A major ingredient of most detergents is phosphate. Phosphates support luxurious growth of algae. Algae withdraw large quantities of oxygen from water, which becomes detrimental to other organisms. Domestic waters are the primary sources of water pollution.

Domestic sewage contributes to the largest amount of waste, and it has been estimated that approximately 20,000 million litres per day (mld) reach the coastal environment of the country. The characteristics of domestic sewage of Bombay is given in Table 4.2.

Table 4.2: *Characteristics of the domestic wastewater pollutants entering the marine environment of Bombay. Daily domestic wastewater output at 1200 mld (approximate)*

Parameter	mg/l	kg/day
Dissolved Solids	1,450*	17.4**
Suspended Solids	245*	2.9**
BOD	258*	3.1**
Sulphate	75*	0.4**
Nitrogen	35*	0.9**
Phosphorus	9*	7,200
Chloride	587*	7
Manganese	507*	608
Iron	2,529	6,035
Cobalt	30	36
Nickel	81	97
Copper	110	132
Zinc	251	301
Lead	11	13

*' one thousand **' hundred thousand

Source: Zingde 1985.

Bombay has the capacity to treat only 390 mld against 1200 mld of domestic sewage. Due to such partial sewage treatment, waste water retains the original characteristics that result into severe damage to water quality. The water quality at Bombay harbour is mentioned in Table 4.3.

Table 4.3: *Levels of various biological and chemical pollution parameters in the Bombay harbour water*

Parameter	**Concentration in water**		**Safe limit**	
pH	7.0		6.5–8.5	
BOD	110–225	mg/l	4.0	mg/l
COD	212–448	mg/l	180	mg/l
Oil and grease	4–15.6	mg/l	1.0	mg/l
Ammonical Nitrogen	0.7–3.5	mg/l	1.2	mg/l
Nickel	30–240	mg/l	0.300	mg/l
Lead	50–100	mg/l	0.100	mg/l
Chromium	ND–20	mg/l	0.200	mg/l
Cadmium	ND–45	mg/l	0.300	mg/l

Source: NEERI 1985; ND–Not Detectable.

The huge discharge of sewage allows the following events that lead to water pollution.

***Depletion of oxygen contents*:** The aerobic bacteria present in water are responsible for the decomposition of organic matter. The quantity of oxygen utilized by the bacteria for the degradation of organic substance is called biological oxygen demand (BOD). Thus, BOD value can be used as an indicator of water pollution. Alongwith BOD, the quantity of oxygen dissolved in a water body (DO) indicates the quality of bio-life in a water system. DO below 4 to 5 ppm is detrimental to the system.

***Promotion of algal growth*:** Stimulation of heavy algal growth and shift in the algal flora to the blue-green algae, leading to the formation of obnoxious blooms, floating scums or blankets of algae results into eutrophication. Most of the algal bloom do not seem to be utilized as food by the invertebrates or zooplankton, thereby minimizing the predatory control. Biological decomposition of such algal masses in turn leads to oxygen depletion. In a poorly oxygenated condition, fish and other animals die and the clean river is turned into a stinking drain.

***Spread of infectious diseases*:** Microorganisms—usually viruses, bacteria, some protozoans and helminths—occur in water bodies as a result of sewage disposal. Consumption of contaminated water causes water-borne infectious diseases.

Organism	Diseases
Viruses	Viral hepatitis, poliomyletitis
Bacteria	Cholera, typhoid, paratyphoid, dysentery, diarrhoea
Protozoa	Amoebiasis, giardiasis
Helminths	Roundworm, hookworm, threadworm

Presence of Escherichia coli in water indicates the degree of water pollution as described below:

Heavily polluted	10,000 l^{-1}
Polluted	1,000 l^{-1}
Slightly polluted	100 l^{-1}
Satisfactory	10 l^{-1}
Drinking water	3 l^{-1}

INDUSTRIAL WATER POLLUTION

Pollution mainly caused by the discharge of industrial effluents into the water body is known as industrial pollution. These effluents contain a wide variety of inorganic and organic substances such as oils, greases, plastics, plasticizers, methylic wastes, suspended solids, phenols, pesticides, heavy metals and acids. Major industries of the country are located on or near the coastline or riversides (Table 4.4).

Table 4.4: *Locations of Major Industries*

State	No. of coastal industrial complexes/industries	Approx. quantity of wastes discharged in kilolitres/day
West Bengal	10 major industries	20,000
Orissa	3 major industries	180
Tamil Nadu	17 major industries	1,237,160
Pondicherry	4 major industries	10,710
Kerala	20 major industries	24,630
Maharashtra	20 industrial complexes	240,065
Gujarat	2 industrial complexes	219,880

Most of the Indian rivers and freshwater streams have been seriously polluted by industrial waste (Table 4.5).

Table 4.5: *Some Indian Rivers and Their Major Sources of Pollution*

Name of the river	Source of pollution
1. Kali at Meerut (UP)	Sugar mills; distilleries; paint, soap, rayon, silk, yarn, tin and glycerine industries.
2. Yamuna near Delhi	DDT factory sewage, Indraprastha Power Station, Delhi
3. Ganga at Kanpur	Jute, chemical, metal and surgical industries; tanneries, textile mills and great bulk of domestic sewage of highly organic nature.
4. Gomti near Lucknow (UP)	Paper and pulp mills; sewage.
5. Dajora in Bareilly (UP)	Synthetic rubber factories.
6. Damodar between Bokaro and Panchet	Fertilizers, fly ash from steel mills, suspen suspended coal particles from washeries, and thermal power station.
7. Hoogly near Calcutta	Power station; paper pulp, jute, textiles, chemical, paint, varnishes, metal, steel, hydrogenated vegetable oils, rayon, and soap, match, shellac, and polythene industries and sewage.
8. Sone at Dalmianagar (Bihar)	Cement, pulp and paper mills.
9. Bhadra (Karnataka)	Pulp, paper and steel industries.
10. Cooum, Adyar and Buckinghum canal (Madras)	Domestic sewage, automobile work shops.
11. Cauvery (Tamil Nadu)	Sewage, tanneries, distilleries, paper and rayon mills.
12. Godavari	Paper mills.
13. Siwan (Bihar)	Paper, sulphur, cement, sugar mills.
14. Kulu (between Bombay and Kalyan)	Chemical factories, rayon mills and tanneries.
15. Suwao (in Balrampur)	Sugar industries.

The discharge of industrial wastes has serious consequences on our environment, some of which are listed here.

(i) Organic substances deplete the oxygen content

(ii) Inorganic substances render the water unfit for drinking and other purposes

(iii) Acids and alkalies adversely affect the growth of fish and other aquatic organisms

(iv) Dye change the colour of water and affect the aquatic life

(v) Toxic substances cause serious damage to flora and fauna

(vi) Oil and other greasy substances interfere with the self purification mechanism of water.

AGRICULTURAL WATER POLLUTION

Water pollution can be caused by agricultural wastes such as fertilizers, pesticides, soil additives and animal wastes that are washed off from the land to the aquatic system through irrigation, rainfall and leaching. India uses about 16 kg/ha of fertilizers on an average. However, the average all over the world is 54 kg/ha. Netherlands alone uses 709 kg/ha. However, an increased use of pesticides has been observed in India—from 2.8 mt in 1975–76 to 6 mt in 1994–95 and 9.7 mt in 1995–96. The demand for these fertilizers will increase the pollution also. Many of these fertilizers are non-biodegradable. In both fresh and marine systems they enter the food chain, accumulate in non-target organisms and multiply inside animal tissues to alarming concentrations. They may find entry into the drinking water supplies.

SOLID WASTE POLLUTION

Solid waste varies in composition with the socio-economic status of the generating community. The following materials could be classified as solid wastes:

- *Garbage*—decomposable wastes from households, food, canning, freezing and meat processing operations that are not disposed of in wastewater
- *Rubbish*—all non-decomposable wastes, garden wastes, cloth, paper, glass, metals and chemicals
- *Sewage*—mostly comprises sludge
- *Miscellaneous materials*—chemicals, paints, explosives and mining wastes.

River or ocean dumping of these materials leads to water pollution. This tends to contaminate surface as well as ground water. Because of a high organic nature of this material, a large BOD is placed on the receiving waters and the sediment becomes coated with highly organic ooze. Non-combustible materials are generally disposed off by ocean dumping.

The National Environmental Engineering Research Institute (Nagpur, India) has categorized sea upto 5 km off Mumbai as one of the most polluted urban centres where 1,800 millions litres of city's discharge is dumped everyday. In 1994, 800 truckloads of garbage was washed onto the Juhu beach in a single night. Others adding to the coastal pollution include foreign liners docking along the Bombay Port Trust (BPT) that openly dump their wastes into the sea and leave a huge trail of fuel along the coastal stretches while departing.

THERMAL POLLUTION

An increase in the optimum water temperature by industrial processes (steel factories, electric power houses and atomic power plants) may be called thermal pollution. Many industries generate their own power and use water to cool their generators. This hot water is released into the system from where it was drawn, causing a warming trend of surface waters. If the system is poorly flushed, a permanent increase in the temperature may result. However, if the water is released into the well-flushed systems, permanent increase in temperature does not occur.

Many organisms are killed instantly by the hot water resulting into a high mortality. It may bring other disturbance in the ecosystem. The eggs of fish may hatch early or fail to hatch at all. It may change the diurnal and seasonal behaviour and metabolic responses of organisms. It may lead to unplanned migration of aquatic animals. Macrophytic population may also be changed. As temperature is an important limiting factor, serious changes may be brought about even by a slight increase in temperature in a population.

OIL POLLUTION

There are about 15 million water crafts on navigable waters throughout the world. Their combined waste discharges are equivalent to a city with a population of 2,000,000. Thus oil pollution, an oxygen demanding waste, is of concern not only from sensational major spills from ships and offshore drilling rigs but also from small spills and cleaning operations.

The information available on oil pollution in Indian oceans is fragmentary. In all, 6,689 observations were made on oil slicks and other floating pollutants along the tanker and trade routes across the northern Indian Ocean. Of these, oil was sighted on 5,582 occasions (Qasim, 1991). The percentage of oil sightings ranged from 51 to 96. The number increased away from the source of oil, that is from the ballast and bilge washings, and northern Indian Ocean is well known for oil slicks.

Observations on the floating petroleum residues from the Indian Ocean region show variations in time and are fairly high occasionally along the tanker routes. In the Arabian Sea, the concentration ranged from 0 to 6.0 mg/m^2 with a mean of 0.59 mg/m^2. The range in the Bay of Bengal tanker route varied from 0 to 69.75 mg/m^2. These figures indicate that the tanker route in the Bay of Bengal is relatively more polluted than the Arabian Sea.

A layer of oil floating on the ocean surface can interfere with the exchange of oxygen and carbon dioxide and reduce the rate of photosynthesis of marine plankton and the respiration of marine animals. Fuel oil added to sea water in very low concentration (199 ppb) depresses photosynthesis.

The death of birds from oil spills has attracted much attention. In the Torrey Canyon incident in 1967, an estimated 40,000 to 100,000 birds died. The Fort Mercer and Pendleton Collision in 1952 reduced the wintering population of elder ducks from 500,000 to 150,000. Some believe that the jackars penguin, which lives in South Africa, is endangered because floating oil from tankers rounding the Cape of Good Hope is killing hundreds of thousands of these birds each year. The chronic effects of oil spills appear less serious than the acute effects.

TOXIC WATER POLLUTANTS AND THEIR HEALTH EFFECTS

Two main categories of water pollutants have been identified from environmental health point of view. The first group comprises conventional water pollutants that come primarily from non-industrial sources and are highly biodegradable, e.g., faecal coliform bacteria, nutrients, nitrates and sediments.

Unlike conventional pollutants, the second group comprises toxic water pollutants, e.g., pesticides, heavy metals, chlorinated hydrocarbons and a variety of inorganic and organic compounds. They are not easily biodegraded and are a serious health problem of highly industrialized countries.

Water Borne Diseases: The burden of water-related diseases in India is presented (in millions of DALYs) in the following chart:

Disease	Female	Male	Total
Diarrhoeal disease	14.39	13.64	28.03
Intestinal helminths	1.0	1.06	2.06
Trachoma	0.07	0.04	0.11
Hepatitis	0.17	0.14	0.31
Total	15.63	14.88	30.51

DALYs = disability adjusted life-years

Coliform Bacteria: The first causal epidemiological connection between human faeces and disease was made by Dr. John Snow in 1854 when he unrevealed the mystery of *London cholera epidemic* by observing that the common link between all the victims in the Broad Street area was that they obtained their drinking water from the same well. Today we know that coliform bacteria make-up something like one-fifth to one-third of the average person's wastes, and billions of them are released into the sewage systems every day. They cause cholera, typhoid fever and gastroenteritis. Chlorination of water is the only remedy, but we should not forget that chlorination may pose health hazards of its own.

Nutrients: Nutrients like phosphorus, nitrogen, and carbon are essential to aquatic life. However, excess of these nutrients in a water body causes paradoxical kind of pollution known as *eutrophication,* the term derived from Greek word meaning *well nourished*. Lake Erie in U.S.A. and Dal Lake in India are facing severe eutrophication problems.

Nitrates: Nitrates occur naturally in water at low levels. However, heavy application of artificial fertilizers, most of which contain nitrogen in the form of urea, may become a health problem. Nitrate levels above 10 mg/l in water can cause *methemoglobinemia* known as *blue baby*. Nitrate levels as high as 40 mg/l have been found in some parts of Midwest.

Sediments: Sediments are the particles of sand, grit and other inorganic matter that flow into waterways from mining sites, construction sites, logging sites and urban run-off. Severe sedimentation can physically fill small ponds and lakes and they may cause turbidity. Mining activities are also one major cause of sedimentation problems.

Acid Rain: The problem of acid rain first came to the attention of scientists in Northern Europe more than thirty years ago when lakes of southern Sweden and Norway were found losing their fish populations. In 70 per cent of some 1,500 lakes analyzed in Norway, pH values were below 4.3 and they contained no fish at all. Acid mists caused by coal-fired plants in Great Britain across the North Sea were carried by prevailing atmospheric currents to Scandinavia. Soon, scientists from other countries reported increased acidity in their waterways. Nearly 200 lakes had been found dead in North America and Canada.

Mercury (Minamata Disease): In 1956, an epidemic of organic mercury poisoning broke out in Minamata, a small town of 50,000 residents located on the coast of Kyushu, Japan's southernmost Island (Fig. 4.3).

It was caused by dumping of mercury wastes into Minamata Bay by Chisso Corporation. Samples taken from the mud of Minamata Bay near Chisso's effluent outlet were found to be contaminated with over 2,000 ppm of mercury. Fish and shellfish samples also contained high methyl-mercury levels ranging from 10 to 40 ppm. Autopsies of the victims revealed levels as high as 70 ppm in liver and 144 ppm in kidney, and 24 ppm in brain, which is acutely sensitive to methyl mercury. Even residents of Minamata town with no outward sign of the disorder had levels ranging from 100–150 ppm in hair samples, normal levels run about 8–90 ppm.

Figure 4.3: Sites associated with Minamata disease

Until the early 1960s, it was widely assumed that elemental mercury emitted or dumped into the biosphere was not a hazard because it did not react easily with other substances, was quite stable, and above all, was found to be only very slightly soluble in water. However, Swedish environmental scientists began to wonder that mercury dumped into the water was in an inorganic elemental form, but the fish that inhabited these waters contained more toxic alkyl form, the methyl-mercury. By 1972, it had been repeatedly demonstrated that aquatic microorganisms living in the bottom sediments of natural waterways had the power to transform the relatively insoluble form of elemental mercury into highly soluble and highly toxic form of methylmercury. Once it has been 'biotransformed' in this way, methylmercury was easily absorbed by the tissues of fish and from these it easily passed to man and other predators that consumed the contaminated fish.

Handigod Syndrome: The indiscriminate use of pesticides in agriculture and public health operations has increased the scope of disruption of ecological balance, as many of the 'non-target' organisms that are important links of food chain perish in the process, thus adversely affecting the secondary and tertiary productivity of fresh water ecosystems. The tragic incident occurred in Karnataka. The villagers consumed the crabs and fish contaminated with pesticide. Many people died and some others fall sick. The incident had been named as "handigod syndrome". Accidental pesticidal poisoning has been reported in Cochin area in 1955 and Sitapur-Hardoi (U.P.) area in 1977.

Among various chlorinated insecticides, viz. DDT, lindane, dieldrin, aldrin, endrin, endosulfan and chlordane examined for their toxicity in fish, endrin has been found to be highly toxic and endosulfan the least toxic. In catfish, endrin was reported to be 70,000 times more toxic than carbaryl.

WASTEWATER TREATMENT

Basic Processes of Water Treatment

The purpose of wastewater treatment is to remove the contaminants from water so that the treated water can meet the acceptable quality standards. The quality standards usually depend upon whether water will be reused or discharged into a receiving stream. Available wastewater treatment processes can be broadly classified as physical, chemical or biological. These processes, which consist of a series of unit operations, are applied in different combinations and sequences depending upon the prevailing situations of effluent concentration composition and condition and specifications of the effluent.

Physical processes are based on exploitation of the physical properties of the contaminants and are generally the simplest forms of treatment. These principally comprise screening sedimentation, flotation and filtration. Chemical processes utilize the chemical properties of the impurities or the added reagents. Commonly used chemical processes are precipitation, coagulation, and disinfection. Other physical and chemical processes such as air stripping, carbon adsorption, oxidation and reduction, ion exchange and membrane processes like reverse osmosis and electrodialysis are also important in certain particular cases. Biological processes utilize biochemical reactions; typical examples are biological filtration and the activated sludge process.

The wastewater treatment processes are generally grouped according to the water quality they are expected to produce. These processes are usually grouped as the primary treatment, the secondary treatment, and the tertiary or the advanced waste treatment. Primary treatment removes identifiable suspended solids and floating matter. In the secondary treatment, also known as the biological treatment, organic matter that is soluble or in the colloidal form is removed. Advanced waste treatment may involve physical, chemical or biological processes or their various combinations depending on the impurities to be removed. These processes are employed to remove residual soluble non-biodegradable organic compounds including surfactants, inorganic nutrients and salts, trace contaminants of various types and dissolved inorganic salts. The advanced waste treatment processes are expensive. and are used only when water produced is required to be of higher quality than that produced by conventional secondary treatment, so that the treated water can be reclaimed and put to some form of direct re-use.

In most cases, water pollution takes place by the industrial or domestic waste water discharger or even by the surface run-off from agricultural field and mined area. Thus, the principal methods of pollution control are centered around the waste water treatment processes. The conventional waste water treatment system has three major steps:

- Primary treatment
- Secondary treatment
- Tertiary treatment

The domestic raw waste water (sewage) or industrial waste water (effluent) treatment processes have some resemblances. The primary objective of this treatment lies on the removal of the following pollutants, so that the treated water could be safely discharged into river, lake or other surface water bodies:

- Total solids (dissolved and suspended)
- Nitrate and phosphate
- Oil, grease
- Toxic metals etc.

Waste Water Treatment Plant

When the waste water (sewage/effluent) reaches the treatment plant, it first passes through a series of screen that remove large objects. Then it passes through primary, secondary and tertiary treatment steps.

(a) ***Primary treatment:*** A series of settling chambers remove heavy grits including coarser organic materials. Then there is a sedimentation clarifier, where suspended particles are oxidised and sedimented at the bottom as sludge. In this process 'considerable amount of suspended solid and organic materials are removed. As such there is substantial lowering of total solids, BOD and COD.

(b) ***Secondary treatment:*** The organic matter and other impurities remaining after the primary treatment are in solution or fine suspension that do not settle and cannot readily be filtered. There are two ways by which finer particles and dissolved materials are sedimented out viz., activated sludge (aerobic) treatment and trickling filter treatment. In the activated sludge process, sewage, after primary treatment, is pumped into an aeration tank, where it is mixed for several hours with air and bacteria-laden sludge. The bacteria then decomposes organic waste along with oxidative sedimentation of suspended and dissolved materials, ultimately leading to sludge deposition at the bottom of the tanks. The effluent from the biological action is still laden with bacteria and is not fit for discharge into open waters.

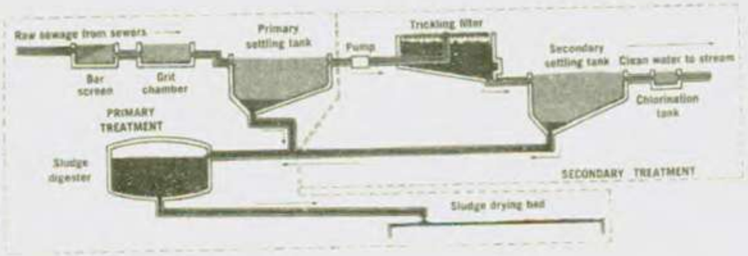

Figure 4.4: *Generalized figure of three stages of waste water treatment process*

An alternative techniques is *'trickling filter'* treatment. In this device, long pipes rotate slowly over a bed of stones. It offers its nutrients in the presence of air to an abundance of rather unappetizing forms of life. A fast moving food chain is set in operation. Bacteria consume molecules of protein, fat and carbohydrates. Protists consume bacteria. Further up the chain are worms, snails, flies and spiders. Each form of life plays its part in converting high energy chemicals to low-energy chemicals. All the oxygen consumed at this stage represents oxygen that will not be needed later when the sewage is discharged to' open water. There, this process constitutes a very significant purification.

Thus, each step in the biological consumption of this water-borne waste, from sewage nutrients to bacteria to protozoa and continuing to consumers of higher orders (such as worms), represents a degradation of energy, a consumption of oxygen and a reduction in the mass of pollutant matter. Finally, when the microorganisms die, their bodies stick together to form aggregates large enough to settle out air in a reasonably short period of time. Some agglomeration also occur in the metabolic processes of the protozoa, so that their excreta are usually larger than the particles they ingest often. Thus, the process of making big particles out of little ones is of prime importance in any system of waste water treatment. The mixture of living and dead organisms and their waste products at the bottom of a treatment tank constitute the 'biologically active sludge'.

(c) ***Tertiary or advanced treatments:*** Although considerable purification is accomplished by the time the waste-water has passed through the primary and secondary stages, these treatments are still inadequate to deal with some complex aspects of water pollution. First, many pollutants in domestic sewage are not removed. Inorganic ions, such as nitrates and phosphates, remain in the treated waters. These materials, as we have seen, serve as plant nutrients and are, therefore, agents of *"eutrophication"*. If there is excess chlorine, it may react with industrial wastes such as organic solvents and produce chlorinated products that are more objectionable than the original pollutants.

Additionally, many pollutants originating from sources such as factories, mines, agricultural run offs and even homes cannot be handled by municipal sewage treatment plants. Some synthetic organic chemicals from industrial wastes are foreign to natural food webs (non biodegradable). They not only resist the bacteria of the purification system, but may also poison them and thereby nullify the biological oxidation. However, several troublesome pollutants, which arise from different industrial units, need special provision for treatment viz. oil separation, phenol recovery, lime treatment, and polyelectrolyte or alum treatment etc. A generalised outline of three stages of waste water treatment process is given in Fig. 4.4.

Waste-water treatment with aquatic macrophytes provided an option for selecting plants in lowcost treatment of municipal and domestic sewage waters. The capacity of ecosystems, which are dominated by aquatic macrophytes, to assimilate and decompose inputs of nutrients and organic matters has resulted in the extended use of such systems to different types of waste waters. In general, municipal and domestic sewage effluents are the rich source of organic and inorganic nutrients (organic carbon, nitrogen and phosphate etc.). Due to higher organic loading, the dissolved oxygen level is very poor. Under such anoxic environment, several aquatic macrophytes can grow and help in the treatment of waste water by removal of BOD, COD, phosphate and nitrate. Thus, constructed wetland can be developed for such kind of waste water treatment using selected macrophytes. This system was practiced in many European countries.

Coagulation and Sedimentation

As mentioned earlier in the discussion of biological treatment, it is advantageous to change little particles into big ones that settle faster. So it is also with inorganic pollutants. Various inorganic colloidal particles are water loving (hydrophilic) and therefore rather adhesive. In their stickiness, they sweep together many other colloidal particles that would otherwise fail to settle out in a reasonable time. This process is called flocculation. Lime, alum, and some salts of iron are among these so-called flocculating agents.

Adsorption

Adsorption is the process by which molecules of a gas or liquid adhere to the surface of a solid. The process is selective—different kinds of molecules adhere differently to any given solid. To purify water, a solid that has a large surface area and binds preferentially to organic pollutants is needed. The material of choice is activated carbon, which is particularly effective in removing chemicals that produce offensive tastes and odors. These include the biologically resistant chlorinated hydrocarbons.

Other Oxidizing Agents

Potassium permanganate and ozone have been used to oxidize waterborne wastes that resist oxidation by air in the presence of microorganisms. Ozone has the important advantage that its only byproduct is oxygen.

Reverse Osmosis

Osmosis is the process by which water passes through a membrane that is impermeable to dissolved ions. In the normal course of osmosis (Fig. 4.5A), the system tends towards an equilibrium in which the concentrations on both sides of the membrane are equal. This means that the water flows from the pure side to the concentrated "polluted" side. This is just what we don't want, because it increases the quantity of polluted water. However, if excess pressure is applied on the concentrated side (Fig. 4.5B), the process can be reversed and the pure water is squeezed through the membrane and thus freed of its dissolved ionic or other soluble pollutants.

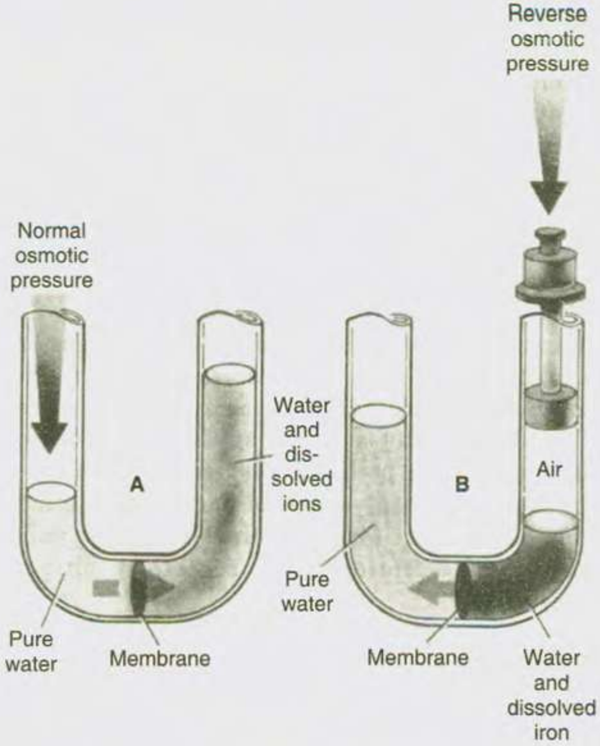

Figure 4.5: Reverse osmosis

Upward Anaerobic Sludge Blanket Technology (UASB)

UASB is a combination of physical and biological processes. The main feature of the former process is the separation of solids and gases from the liquid, and that of the latter, degradation of decomposable organic matter under conditions that do not require oxygen. The treatment tank (Fig. 4.6) consists of an up flow reactor with a feed inlet distribution system at its bottom and a gas-solid-liquid (three phase) separator at the top. The wastewater enters the reactor from the bottom and flows upwards through the sludge bed in the digestion compartment. The sludge bed contains microorganism capable of thriving in an oxygen-deficient environment. The bed traps the solid material, which is degraded by the organisms, producing methane or biogas and carbon dioxide in the process. The biogas provides a gentle mixing in the sludge bed promoting breakdown and a reduction in levels of 55 and BOD. The methane is collected at the top of the reactor in a gas collector from where it is withdrawn, while the water-sludge mixture enters co-settling tank where the sludge settles down and flows back into the bottom of the reactor.

Retention of bacteria-containing sludge is one of the most important features of the UASB process. The bacteria in the sludge keep on with their function of treating the incoming effluent. The continuous bacterial presence and activity enables retention time in the reactor to be reduced to about six to eight hours compared to at least 30 hours that is required in conventional sewage systems.

The water is collected in gutters and discharged out of the reactor. The sludge is periodically shifted into drying beds to be used as a enriched soil. The methane generated can be used as gas for domestic or industrial use. Also, after appropriate dehydration and cleaning, it can be used to generate electricity for running the plant. The process can be reactivated even after the plant has remained shut for months, or after power breakdowns and interruptions in wastewater supply.

Benefits of UASB

- Low space requirement
- Low sludge production with quick dewatering characteristics
- Lesser and simpler electromechanical parts used, leading to low operation and maintenance costs
- Low power requirements and ability to withstand long power failures
- Sludge digestion quicker compared to conventional digesters
- Generation of biogas, which can be used to produce electricity

CASE STUDIES OF WATER POLLUTION

Eutrophication of Medical Lake in Washington

In the summer of 1971, Medical Lake in Washington became clogged with algae and bacteria and turned a dark, turbid green. Fish, algae, and bacteria died, and the wind blew them into stinking masses on the sea shore. It was apparent that Medical Lake was dying due to eutrophication.

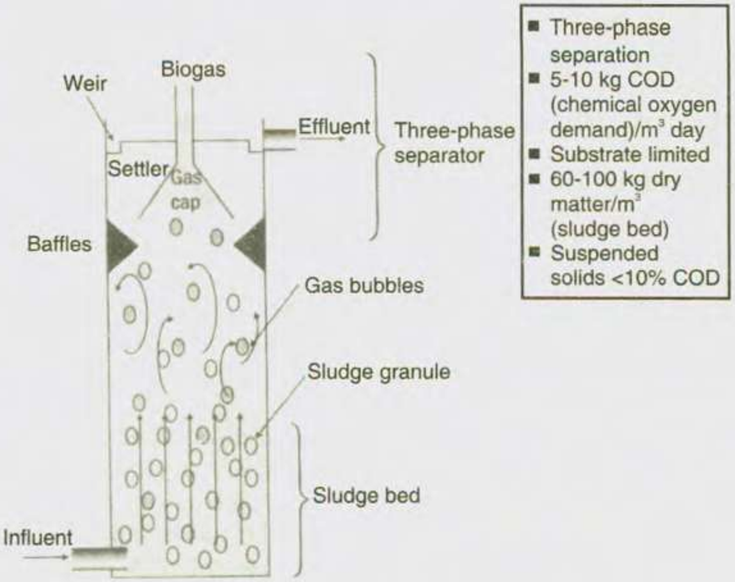

Figure 4.6: *Upward-flow anaerobic sludge blanket technology*

Fish in the lake did not die from a direct effect of pollution from disease organisms in the polluted water or from something in the polluted water that was directly toxic to them. They died as the result of an ecosystem effect—the complex effect produced by a community of interacting organisms exerted through the local environment and involving that environment.

Problems associated with the artificial eutrophication of bodies of water are not restricted to freshwater lakes. In recent years, concern has grown about the outflow of sewage from urban areas into tropical coastal waters and the possible effects of eutrophication on coral reefs. Such concern has grown for the famous Great Barrier Reef of Australia, an important area for biological diversity and recreation as well as some reefs forming the Hawaiian Islands. Eutrophication can be a natural process. What happened to Medical Lake is artificial eutrophication (sometimes also called *cultural eutrophication).* A lake that has a high concentration of chemical elements required for life is called a *eutrophic lake;* one that has a relatively low concentration of these elements is called an *oligotrophic lake.*

Oligotrophic lakes are relatively sterile and therefore have clear waters that are pleasant for swimmers and boaters. Eutrophic lakes have an abundance of life, often mats of algae and bacteria that are unpleasant. In contrast to the typical idea of what is desirable in nature, low nutrient conditions are generally preferred by people when it comes to lakes for swimming and boating.

Love Canal Episode

One of best examples of ground water pollution is the Love Canal near Niagara Falls, New York, where burial of chemical wastes caused serious water pollution and health problems. From 1920s to the 1950s, more than 80 different chemicals were dumped there. In 1953, the company donated the land to the city of Niagara fall. Eventually, township developed. Years later in 1975-76, heavy rainfall and snowfall set off the events that led to Love Canal catastrophe. Trees and garden began to die. Bicycle tires and rubber shoes disintegrated. The old dumpsite contained a number of substances that were suspected to be carcinogens including benzene, dioxin, dichloroethylene and chloroform. Residents of the area had higher miscarriages, birth defects, liver and blood abnormalities and chromosome damage. More than $100 million were spent to clean up the Love Canal site and rehabilitate the residents. In addition, approximately $3 million/year may be needed to monitor the area for future.

STUDY QUESTIONS

1. Discuss the physico-chemical nature of fresh water.
2. Discuss the physico-chemical nature of marine water.
3. Write an assay on water pollution.
4. Discuss in detail the health effects of toxic water pollutants.
5. Describe different methods used to determine water pollution.
6. Write short notes on the following:
   - (a) Hydrologic cycle
   - (b) Water budget
   - (c) Oil pollution
   - (d) Thermal pollution
   - (e) Solid waste pollution
   - (f) Minamata disease

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5

Lithosphere, Land and Soil Pollution

INTRODUCTION

The solid component of earth is called lithosphere. It consists of different layers, viz. crust, mantle, outer core and inner core (Fig. 5.1). The crust is the outermost solid layer of the earth. It is composed of different kinds of rocks, which as a whole, has the density and composition of granite. Hence, the layer lining the floor of continents is called granite layer. The "basaltic layer" underlines the oceanic floor and forms the thick part of earth's crust. Earth's crust is the only part that supports biotic communities by providing them food, shelter and anchorage. Therefore, the soil forms the most important ecological factor.

ZONAL STRUCTURE OF THE EARTH

Most of the information on the structure of the earth is derived from analysis of seismic (or earthquake) waves. An earthquake gives rise to different types of waves, of which two can penetrate the body of the earth. These are:

1. Primary waves or P waves, which are transmitted in the direction of propagation of earthquake and possess small amplitude.
2. The secondary waves or S waves, which are transmitted perpendicular to the direction of propagation of earthquake and possess large amplitude.

The velocities of P and S waves depend on the density of the material through which they pass. In the region of discontinuity, that is, where the density of the material changes, the P and S waves are subjected to reflection and refraction. This causes a change in their velocities. By comparing the velocities of P and

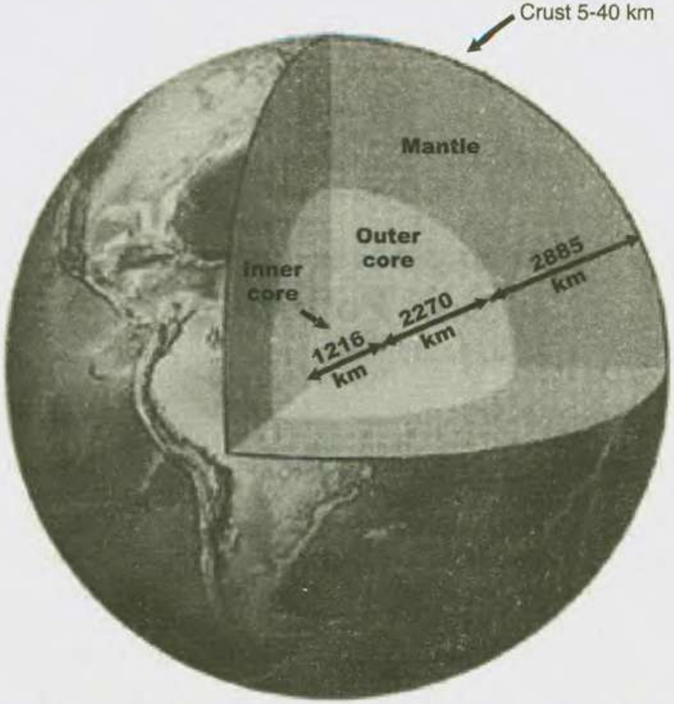

Figure 5.1: *View of Earth's layered structure. The inner core, outer core, and mantle and drawn to scale but the thickness of the crust is exaggerated by about five times*

S waves at different depths of the earth, it has been concluded that the internal terrestrial structure is heterogeneous and that two prominent discontinuities are present—the *Mohorovicic discontinuity* and the *Wiechert-Gutenberg discontinuity.* These are called the *first order discontinuities*. They divide the earth into the following three zones:

(a) *Crust,* from the surface of the earth to Mohorovicic discontinuity
(b) *Mantle,* from the Mohorovicic discontinuity to the Wiechert-Gutenberg discontinuity
(c) *Core,* from Wiechert-Gutenberg discontinuity to the centre of the earth

The zonal structure of the earth is depicted in Fig. 5.1. The first order discontinuities are shown by broken lines. The mantle is further subdivided into upper mantle and lower mantle by a transition zone. The transition zone also represents a discontinuity. However, since the variation of density between upper and lower mantles is not much, therefore, such a discontinuity is termed *second order discontinuity* and shown by inclined lines in Fig. 5.1. Likewise, the core is also subdivided into outer (or upper) core, which is in liquid state, and inner (or lower) core, which is in solid state, by a second order discontinuity.

The crust and the upper mantle together constitute the *lithosphere.* Some physical characteristics of crust, mantle and core are presented in Table 5.1. The chemical composition of the three zones are described in sequel.

Table 5.1: *Physical Characteristics of Earth's Zones*

Zone	Thickness (km)	Volume ($\times 10^{-27}$ cm^3)	Mean density (g cm^{-3})	Mass ($\times 10^{27}$)	Mass (per cent)
Crust	17	0.008	2.8	0.024	0.4
Mantle	2,883	0.899	4.5	4.075	68.1
Core	3,471	0.175	10.7	1.876	31.5
Whole earth	6,371	1.082	5.5	5.975	100.0

Composition of the Crust

From the stand point of environment of life on earth, it is the crust that is of prime significance, for it contains the continents and the oceans, the soil and the sediments, the water and the minerals. The average composition of the important elements in the earth crust is given in Table 5.2.

The eight elements listed in Table 5.2 make-up nearly 99% of the total crustal composition by weight. Of these, oxygen is the most predominant. The earth's crust contains largely oxygen compounds, especially silicates. The silicates of aluminium, calcium, magnesium, sodium, potassium and iron are found in abundance. Therefore, silicon is the second most abundant element in the earth's crust.

Table 5.2 *Composition of the Crust*

Major elements	Per cent by weight	Per cent by volume	Per cent by atoms
Oxygen	46.6	93.8	62.6
Silicon	27.7	0.9	21.2
Aluminium	8.1	0.5	6.5
Iron	5.0	0.4	1.9
Calcium	3.6	1.0	1.9
Sodium	2.8	1.3	2.6
Potassium	2.6	1.8	1.4
Magnesium	2.1	0.3	1.8

As is evident from Table 5.1, the oxygen composition exceeds 60 per cent in terms of the number of atoms. If the volume of different atoms (or ions) is calculated, oxygen makes up more than 90 per cent of the volume. Thus, in brief, the crust of the earth is essentially a packing of oxygen anions in form of silicates.

If we were to extend Table 5.2, the ninth place would be occupied by titanium, which would be followed by hydrogen, phosphorus, barium and strontium. Surprisingly, some of the elements that play an important role in our economic life and have long been known to and used by man are actually quite rare. For example, ziroconium is more abundant than copper; lead is almost as abundant as gallium, and lanthanides (or the so called rare earths) and vanadium are more abundant than mercury and tin respectively. Elements like titanium, ziroconium or the rare earths, which are normally thought to be scarce, are in fact present in the crust in considerable amounts but are systematically dispersed throughout the crust and never occur at one place in high concentrations. These are, therefore, called *dispersed elements.* On the other hand, elements like zinc, copper or lead, which are normally thought to be abundant are in fact quite scarce, but have been concentrated into rich ores at a few scattered locations in the crust.

Composition of the Mantle

As is evident from Table 5.3, the mantle represents about 68 per cent of the mass of the earth. Figure 5.1 reveals that the mantle is subdivided into the upper, transition and the lower zones.

The *upper mantle* extends from the Mohorovicic discontinuity to about 400 km. This region contains predominantly three silicate materials: olivine, $(Mg, Fe)_2SiO_4$; pyroxene, $CaO.MgO.2SiO_2$ and garnet, $(Ca, Mg, Fe, Mn)_3(Al, Fe, Cr)_2.Si_3O_{12}$.

The *transition zone* extends from a depth of about 400 km to about 1000 km. The three components of the upper mantle, viz. olivine, pyroxene and garnet, are also present in this region, but in chemically modified forms. At a depth of about 350 km, pyroxene forms a solid solution with garnet. At about 400 km, olivine undergoes a phase transition to *b*-olivine, *b*-$(\mathrm{Mg, Fe})_2.\mathrm{SiO}_4$. The latter is transformed to *g*-olivine, *g*-$(\mathrm{Mg, Fe})_2.\mathrm{SiO}_4$ at about 550 km. In the region 650–1000 km, the $\mathrm{Mg_2SiO_4}$ component of *g*-olivine disproportionates into magnesium silicate ($\mathrm{MgSiO_3}$) and magnesium oxide (MgO). Magnesium silicate combines with alumina ($\mathrm{Al_2O_3}$) to form a solid solution.

The *lower mantle,* which extends from a depth of about 1,000 km to about 29,000 km, consists of a mixture of oxides formed due to disproportion in transition zone minerals under pressure. The main components are magnesium oxide, iron oxide and silica.

The overall composition of the mantle may be expressed either in terms of percentage of elements or in terms of percentage of oxides (Table 5.3).

Table 5.3: *Composition of the Mantle*

Major elemental composition		Major oxide composition	
Element	**Per cent by weight**	**Oxide**	**Per cent by weight**
Oxygen	44	$\mathrm{SiO_2}$	48
Silicon	23	MgO	31
Magnesium	19	FeO	13
Iron	9.9	$\mathrm{Al_2O_3}$	3
Calcium	1.7	CaO	2.3
Aluminium	1.6	$\mathrm{Na_2O_3}$	1.1
Sodium	0.84	$\mathrm{Cr_2O_3}$	0.55
Chromium	0.38	MnO	0.43
Manganese	0.33	$\mathrm{P_2O_5}$	0.34
Phosphorus	0.14	$\mathrm{K_2O}$	0.13
Potassium	0.11	$\mathrm{TiO_2}$	0.13
Titanium	0.08		

As in the case of the crust, oxygen is the most predominant element in the mantle too. Most of the oxygen in the upper mantle and transition zone is present in the form of silicates, and therefore, silicon is the second most abundant element in the mantle. But in the lower mantle, oxygen is present as oxides. From Table 5.3, the following inference may be drawn as far as the composition of oxides is concerned.

1. More than 90 per cent by weight of the mantle is represented by the system FeO-MgO-SiO_2, and no other oxide exceeds 4 per cent in the mantle.
2. If the components, Na_2-CaO-Al_2O_3 are added, then this accounts for more than 98 per cent and no other oxide exceeds 0.6 per cent in the mantle.

Composition of the Core

The outer core extends from the depth of about 2,900 km to about 5,080 km, while the inner core extends from about 5,080 km to about 6,370 km. The inner core, which is in a solid state, contains nearly pure iron, while the outer core, which is in a liquid state, also contains predominantly iron. However, when the density of the outer core is compared with that of pure iron under the pressure and temperature conditions prevailing within the core, it is found to be 8–10 per cent less dense than expected. This discrepancy implies that the outer core contains about 5–15 per cent of an element or elements of lower atomic weight than iron. One of the companions of iron in the outer core is nickel. In fact, the outer core is predominantly an iron-nickel alloy. Yet, the addition of nickel to iron does not completely overcome the discrepancy in density value. A further addition of a still lighter element is necessary in order to explain the observed density measurements. This lighter element is a subject of considerable controversy and debate.

One school of thought considers sulphur to be the principal light element in the outer core. However, a formidable problem confronting this hypothesis is that sulphur is quite a volatile element. Its deficiency factor is about 0.7. It is, therefore, likely that sulphur would be depleted in the core, where the temperature is nearly 7500°C. Further, elements like chromium, manganese, sodium, rubidium, cesium and zinc, which are less volatile than sulphur and have lower deficiency factors (0.03–0.3) are not found in the core. It is, therefore, difficult to explain as to how sulphur is retained, while the less volatile elements are depleted in the core.

Another school of thought suggests that the density of the outer core can be explained if it is assumed to contain a mixture of about 60 per cent liquid iron (II) oxide, and 40 per cent liquid Fe-Ni alloy. The Fe-Ni alloy has approximately the following composition: Fe, 94.5 per cent; Ni, 5.5 per cent.

Minerals and Rocks

Minerals are naturally occurring inorganic crystalline substances with physical and chemical properties within prescribed limits.

Rocks are aggregates of a mineral or minerals. There are over 2,000 minerals, however, only a few are necessary to identify most of the rocks. Nearly 75 per cent by weight of the earth's crust is oxygen and silicon, and these two elements in combination with aluminium, iron, calcium, sodium, potassium and magnesium account for the minerals that make-up about 95 per cent of Earth's crust. Minerals and rocks are the foundation materials for the soils. Their composition, texture and structure determine the type of the soil.

Rock cycle is truly the largest of the earth cycles. This cycle depends on the tectonic cycle for energy, the geochemical cycle for materials and the hydrologic cycle for water.

SOIL

It is the shallow body of material found on the surface of the land, derived directly or indirectly from weathered mantle rock in association with organic detritus, water, air and living organisms. Soil is the habitat of microorganisms and burrowing animals. Moreover, it supplies materials to indwelling members of the biota.

Development of Soils

We know that there are three kinds of soil-forming rocks, viz. igneous rocks, sedimentary rocks and metamorphic rocks. Soil formation results from the disintegration or weathering of parent rocks by physical, chemical or biological agents. As a result, small particles called regoliths are formed. Regoliths, under the influence of other pedogenic processes, finally develop into mature soil. The processes of soil formation are discussed here in detail.

(i) ***Physical weathering:*** When climatic agents such as temperature, water, ice, and gravity change the rocks in regoliths but do not cause any chemical transformation of rocks, the process is called *physical weathering*. It occurs in deserts, at high altitudes and latitudes, specially at places where sparse vegetation grows over the rocks.

(ii) ***Chemical weathering:*** Due to physical weathering, rocks are exposed to chemical weathering that occurs simultaneously and continues for a long period after that. Here the chemical transformation of parent minerals occurs to form new mineral complexes. Water is the most potent weathering agent. Soluble rocks like gypsum, limestone and those with a calcareous content get weathered by the solvent action of water. Hydrolysis allows the exchange of constituent parts between water and minerals. As a result, hydroxides of iron, magnesium, calcium and aluminium are formed. The release of calcium, magnesium, potassium and sodium as well as hydrations further contribute to chemical weathering.

(iii) ***Biological weathering:*** Certain organisms like bacteria, protozoans, fungi and nematodes as well as lichens and mosses colonize the rocks and transform them into a dynamic system storing energy and synthesizing organic material. Their activities change the physical structure of the rock. The lichens and mosses extract mineral nutrients such as P, S, Ca, Mg, K, Na, Fe, Si and Al from the rock. They combine with organic matter and eventually return to the developing soil after the decomposition of vegetation.

SOIL/LAND POLLUTION

The weathered earth crust forms soil over the centuries that supports the variety of microscopic and macroscopic life-forms. The process of soil formation is very complex, involving a number of physical, chemical and biological transformation. The topmost layer of soil is comparatively more rich in nutrients and supports maximum bio-forms. It is composed of minerals of various sizes and organic matters along with pore space filled with air and water. In deeper layer soil nutrients and other associated properties varies distinctly. Thus, there are a number of zones one cannot notice when a soil profile is made for analysis of soil depth. The profile character varies distinctly from place to place, particularly with respect to their depth, colour and composition.

There are different classes of soil types, primarily based on the particle size distribution pattern.

There are various ways of addition and losses of nutrients that take place in soil. This nutrient cycling makes the balance between organic and inorganic soil constituents.

Biological soil has a large number of biota living inside. They are categorized as algae, fungi, bacteria, actinomycetes, microarthropods, protozoans and nematodes. Many such biota help in decomposition of soil, organic materials and in nutrient cycling. It is further interesting to note the fact that soil itself acts as a ecosystem with diverse forms of life—those which could be easily arranged in various trophic tiers. There is also a food web among these organisms. The more the complex food web vis-a-vis higher diversity of life forms in soil, the better it is for soil health.

However, over the years, soil gets contaminated by a number of ways, which is popularly known as soil pollution/land pollution. The major routes of contamination of land/soil are shown in Table 5.4.

There is a continuous elemental cycle operated in soil by microbes in addition to sustained addition and loss of nutrients from soil by various activities, resulting in the rapid

Table 5.4: *Major Routes of Contamination of Land*

Route	***Major pollutants***	***Comments***
Waste-dumping including rubbish dumps/landfall sites/industrial dumps	A very wide range of different pollutants	Some industrial dumps are high in particular pollutants, e.g. oil, metal ore deposits, PCBs
Application of pesticides to agricultural land and forests	Insecticides, rodenticides, herbicides and fungicides as sprays, dusts, seed dressings, etc.	In most countries there area strict regulations controlling the application of pesticides
Control of insect vectors of disease	Insecticides	
Application of sewage to agricultural land	Heavy metals, nitrates, detergents	Major pollution over large are as a conse-quence of control mea-sures against malarial mosquito and fly
Flooding by rivers or seas Precipitation from air as dust or droplets, or in rain or snow	A variety of pollutants including those associated with sewage	Transport may be over short distances (spray drift, soot and dust from chimneys) or long distance (brought down especially by rain and snow)
	Pollutants associated with soot and dust, acid rain, pesticides	

transformation of soil nutrition in both short and long-term basis.

Types of Land/Soil Pollution

Soil gets polluted by a number of ways. The major kinds of soil pollution are:

- Acidification
- Salinization and sodification
- Agrochemical pollution
- Contamination by metalliferous wastes

Acidification

Acidification has a number of natural and anthropogenic causes. The main natural causes are long-term leaching and microbial respiration. The acids found in rainwater (carbonic acid) and in decomposing organic material (humic and fulvic acids) can stimulate leaching by dissociating into H^+ ions and their component anions, which then displace or attract base cations from the soil exchange complex. Leaching of bases is most common where precipitation exceeds evapotranspiration and includes many eastern parts of North America and northwestern parts of Europe, where soils have been subjected to leaching throughout most of the 10,000–15,000 years of postglacial time. Microbial respiration also leads to soil acidification owing to the production of CO_2 (carbon dioxide), which gets dissolved in soil water to form carbonic acid. Other natural processes associated with soil acidification (change in the pH) are plant growth and nitrification. During plant growth, nutrient base cations are obtained through root systems in exchange for H^+ ions, thus leading to increased soil acidity. Nitrification is an oxidative process of organic decomposition, whereby NH_4^+ (ammonium) ions are converted to NO_3^- (nitrate) ions by nitrifying bacteria, with H^+ ions as a byproduct:

$$NH_4^+ + 1.5\ O_2 \Rightarrow NO_3^- + 4H^+$$

These ions are then available for displacing and attracting base cations from the soil exchange complex, as mentioned above, thus leading to soil acidification (Table 5.5).

Table 5.5: *Causes of Soil Acidification*

Source		**H^+ addition or equivalent (change in pH)**
Natural	CO_2 in soil pH> 6.5 (calcareous soils)	7.2–12.8
	Organic acids in acid soils and from vegetation	0.1–0.7
Acid "rain"	Wet deposition	0.3–1.0
	Dry deposition	0.3–2.4
	NH_3 and NH_4^+ oxidation	0.7
Land use	Cation excess in vegetation	0.2–2
	NH_4^+ oxidation (agricultural soils) and leaching	4–6
	Oxidation of N and S from organic matter and leaching	0–10

Source: Rowell and Wild 1985

The main anthropogenic causes of acidification include certain land use practices, such as needleleaf afforestation, excessive use of inorganic nitrogen fertilizers, land drainage and acid deposition resulting from urban and industrial pollution. Needleleaf afforestation has been associated with the acidification of soils and surface waters for a number of reasons. First, needleleaf trees produce litter, which is very acidic in comparison with most broadleaf species. Second, because of their high canopy surface area, needleleaf trees are able to 'scavenge' acid pollutants from the atmosphere, later releasing them into the soil via throughfall and stemflow. Third, due to modifications of the surface and soil hydrology by drainage channels and shallow root networks, water transfer is rapid and is concentrated either at the surface or in the uppermost layer of the soil. Under these conditions, the residence time of the water in the soil is limited, as is the depth to which it can percolate. Thus, the contributions of weathering and ion exchange reactions to the buffering process are limited (Bache 1983, Miller 1985).

Excessive use of inorganic nitrogen fertilizers in agricultural systems has also been associated with soil acidification, partly through the process of nitrification. If levels of NO_3^- ions in the soil are in excess of plant requirements, they will behave as mobile anions, thus encouraging the leaching process. The acidifying effect of nitrogen fertilizer mobilized in the form of soluble organo-metallic complexes. If mineral acids, however, predominate, then aluminium is mobilized in its ionic, labile-monomeric form (Al^{3+}). This form of aluminium is particularly toxic to many freshwater organisms including fish. In a similar way, aluminium and heavy metals, such as lead, zinc and cadmium are more readily mobilized in acidic soils.

Acidification of soils and associated nutrient leaching have also been implicated in damage to trees in forested areas, particularly in Central Europe and Scandinavia. It is more likely, however, that nutrient leaching acts synergistically with other factors, including ozone pollution, acid deposition, NH_4^+ (ammonium) uptake, drought and frost to produce stress in the tree. Signs of tree damage include needle discolouration, crown defoliation and deformed branch structures. Increased soil acidity and associated changes in aluminium mobility also have serious implications on the quality of surface waters, which receive drainage from acidified soils.

Soils vary dramatically in their ability to buffer acidity, a characteristic known as the *buffering* or *acid neutralizing capacity*. The buffering capacity of a soil is defined as the amount of acid that needs to be added to cause a reduction in pH of one unit (Trudgill, 1988). Soils which contain significant quantities of base-rich, weatherable minerals have a high buffering capacity, whereas those which are dominated by quartz and similarly, resistant minerals have a low buffering capacity. In Britain, for example, soils with the highest buffering capacities are found in eastern and southern areas where calcareous parent materials are particularly common. Soils with the lowest buffering capacities are found in areas with base-poor, often siliceous, parent materials which predominate in upland areas in the west and north.

There are a number of approaches to the management and remediation of soil and surface water acidity, including liming, sensible forestry management and reduction of acid emissions into the atmosphere. Liming has long been practised on agricultural land to remedify the problems of modification, slow organic matter turnover, poor modulation in some legumes, calcium and molybdenum deficiency and aluminium and manganese toxicity. Liming materials most commonly used include ground limestone, chalk, marl and basic slag, the main active constituent being $CaCO_3$ (calcium carbonate); other minor components include quicklime (CaO), slaked lime ($Ca(OH)_2$) and $MgCO_3$ (magnesium carbonate). The lime requirement of a soil varies depending on its buffering capacity and is usually expressed as the amount of $CaCO_3$ (t ha^{-1}) required to raise the pH of the top 15 cm of soil to the desired value. In temperate areas, the ideal soil pH is about 6.5 for arable crops and about 6.0 for grasslands. In tropical areas, however, pH values of about 5.5 are often preferred, particularly in soils with high exchangeable aluminium contents, where phosphorus availability may be restricted under more alkaline conditions.

Salinization and sodification

The term *salinization* defines the impregnation of soils by various salts, especially calcium sulphate (gypsum: $CaSO_4$, $2H_2O$) and sodium sulphates (especially thenardite, Na_2SO_4), and in most advanced cases, various magnesium sulphates (epsomite) and sodium chloride (halite). They precipitate from the groundwater by percolating vertically through capillary under the influence of evapotranspiration during episodes of drought, and not from the evaporation of stagnant water on impermeable soils. They dissolve again and seep downwards when rain occurs, hence an alternative vertical motion of salts occurs with time.

Dissolved ions that cause salinization have various origins—they are carried by incoming waters, or are produced by the leaching of the detrital minerals (such as feldspars) in the soil, or the weathering of nearby igneous outcrops (as occurs in the Nordeste region of Brazil). In many cases their origin is the remobilization of fossil salts, which were deposited in the soil itself during earlier dry climatic episodes and kept there for millennia. Another important source of salts may be particles carried in from distant areas by the blowing out of saline efflorescences (sea or salt deserts). The process of salinization requires two hydrogeological factors: (i) disequilibrium of the balance of input and output of water in soils when the evaporation flux is generally higher than the water inflow (precipitation, surface or groundwater flow), (ii) absence or insufficiency of drainage due to the topographic location or to the stratigraphic inclination of the subsoil strata, which prevents the elimination of saline waters. Flat desert or steppe plains are the essential sites of salinization.

Salinization usually occurs *per ascensum* when capillary water brings up phreatic water, and when supersaturation of dissolved salt occurs through evaporation. Therefore, excess irrigation, which shifts the groundwater level, is an important cause of soil salinization.

Experiments in arid Turkmenistan on irrigated but poorly drained plantations have shown that salinization begins after two years at a depth of about 20 cm and attains a depth of one metre after 30 days. Tree roots accelerate salinization. Two phenomena occur in salinization: the disorganization of the matrix of the soil, and the deposition of soluble salts (Duchaufour, 1977).

Agrochemical pollution

At the end of the 19th century, farmers started using artificial fertilizers, enabling more land to be brought into cultivation. An additional benefit is that artificial fertilizers are cleaner and become less dependent on manure. However, the production of man-made fertilizers requires large amounts of energy and depletes the world's resources of phosphate ore. Moreover, in areas with large concentrations of livestock, the use of artificial fertilizers can give rise to large surpluses of manure. The easy way out is simply to dump these surpluses on fields or even soils, surface water and groundwater with nitrogen, phosphorus, potassium and heavy metals. Another problem is that the large quantities of manure kept in stables and sheds are a source of ammonia emission, a key element of acidification. Ammonium is also emitted when manure is spread over fields, a practice that also causes localized odour problems.

In recent decades, the use of inorganic fertilizers has increased dramatically at the expense of more traditional organic nutrient treatments. Between 1952 and 1985, the global use of fertilizers increased from 14 million tonnes to 125 million tonnes, an increase of almost 900 per cent. Inorganic fertilizers are used in preference to organic treatments because the nutrients are in a more readily available form and are released rapidly after applications.

A wide range of pesticides has been developed (more than 450 compounds). The types most commonly used are insecticides, fungicides and herbicides, while other varieties include nematicides, miticides, rodenticides and molluscicides. Pesticides behave in a variety of ways depending upon their applications.

They may be degraded biologically or photochemically, adsorbed by organic matter, clay and oxides/hydroxides of iron and aluminium, washed into water courses by leaching (especially compounds with solubilities > 10 mg such as simazine, bromacil and aldicarb) and surface runoff, or they may undergo volatilization into the atmosphere (especially surface applied compounds and those of low solubility and vapour pressure such as organochlorines).

Contamination by metalliferous wastes

Metalliferous wastes, particularly heavy metals (e.g., lead, zinc, cadmium, copper and nickel), are commonly found in soils of areas where ore extraction and smelting have occurred. Metal contamination occurs on land used for scrap metal dealing and ammunition factories. In an attempt to provide systematic data or the extent of heavy metal contamination in urban soils in Britain, a national survey was commissioned by the Department of Environment in 1981, for which 100 household gardens were sampled in each of 53 cities, towns and villages. In most of these localities, total lead levels in the soil exceeded 200 mg kg^{-1}, with values in excess of 500 mg kg^{-1} in industrial areas in the south and in former lead mining areas in the north. These values are considerably greater than the background levels of lead (usually < 100 mg kg^{-1}) normally found in uncontaminated soils.

Toxic metals may exist in the soil in a number of forms including adsorbed cations attached to clay and humus colloids and organometallic chelates. Their availability to plants depends on a number of soil metals. In soils with a low CEC, the metals are not retained effectively and are likely to be either leached from the soil or taken up by plants, while in soils with a high CEC, they are likely to be fixed in the soil through adsorption processes. Similarly, the mobility and availability of heavy metals is considerably greater in acidic soils ($pH < 5.5$) than near neutral or alkaline soils. Once mobilized, the metals may enter the food chain either through water supplies and aquatic organisms, or through arable produce and grazing animals. The effects of toxic metals in soils on human health are unclear and it is, therefore, difficult to establish threshold concentrations above which toxicity problems are likely to occur. However, a number of countries have devised such threshold values, although these vary markedly in response to differences in environmental policy and legislation. The Dutch government, for example, has a system with three levels—an acceptable reference or background value, an indicative value for further investigation and an indicative value for clean-up.

SOIL CONSERVATION

Although our soils have been formed over long periods of time, some of them are being destroyed within a span of few years. An estimated 6–7 million hectares of agricultural land are now made unproductive each year due to erosion throughout the world. Waterlogging, salination and alkalinization reduce the productivity of an additional 1.5 million hectares each year. Between 1980 and 2000, an estimated 1.4 billion hectares will be lost to city growth at the global level.

In India, out of a total area of 329 million hectares, 175 million hectares of land require a special treatment to protect the soil. One hundred and fifty million hectares have been eroded by wind, 8 million hectares by salinity and alkalinity and 7 million hectares by river action and other factors. Therefore, the National Conservation Strategy and the Policy Statement on Environment and Development has set certain guidelines for land and soil management:

1. Survey of all India soil and land use.
2. Treatment of catchment areas in selected river valley projects and integrated watershed management in catchment of flood prone rivers.
3. Assistance to states to control shifting cultivation.
4. Assistance for reclamation and development of ravine areas.
5. Desert development programme.
6. Drought prone areas development programme.

In recent years, soil scientists have been greatly concerned with the problems associated with soil management. Heavy doses of chemical substances, mineral fertilizers, pesticides and fungicides have contributed to acidity or alkalinity of the soil. Various kinds of air pollutants, specially the acid rains, exert harmful effects on soil (Kvoda, 1972).

Modern agricultural practices can counter the above processes of soil degradation. A series of remedial measures such as contour and strip farming, forest plantations in rows and clumps, a regular sowing of grass, rotation of crops, and preferential use of organic than inorganic manures have been suggested.

The soil system is a living community consisting of microbes, algae, fungi, protozoans, insects, annelids and fossorial animals. It contains many chemical substances formed by weathering and decay of organic material. Microbes oxidize these substances to inorganic oxides that later on become the part of geochemical cycles. Proper global, national, regional and local land use planning can protect soil degradation.

STUDY QUESTIONS

1. Describe the zonal structure of Earth.
2. Give an account of the development of soil.
3. Write an essay on land pollution.
4. Write short notes on the following:
   (a) Soil acidification
   (b) Soil salinization
   (c) Soil conservation

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6

Noise Pollution

INTRODUCTION

Noise is the unwanted sound. The word has been derived from a Latin word 'nausea' meaning noise. Sound is a form of energy. The environmental effects of noise depend not only on total energy but also on the sound's pitch or frequency and its time pattern. The apparent noise that is perceived by human ear depends on both the frequency and intensity of sound. The intensity of the sound is measured in decibels (d = deci meaning 10, B = Bell after the name of scientist Alfred Grahm Bell). Technically, a decibel (dB) is the amount of sound pressure that equals to 0.0002 microbars (energy of about 10^{-15} watts). Since loudness is measured in logarithmic scale, dB can be represented as:

$$\mathrm{dB} = 10 \times \log 10 \frac{I}{I_0}$$

where I is the measured sound intensity and I_0 is the softest audible sound intensity. One decibel is the faintest sound intensity which can be perceived by human ear, and it can tolerate upto 180 dB. The frequency is defined as the number of vibrations and is denoted by Hertz (hz). One hertz is equal to 1 vibration second^{-1}. Man can hear sound from 16 to 20,000 hz. The range of vibrations below 16 hz are infra-audible and those above 20,000 hz are ultrasonic. Many animals can hear sounds that are inaudible to human ear. The loudness can also be expressed in sones. One sone is equal to 40 dB at a pressure of 1,000 hz. Sometimes the sound is expressed in psychoacoustic terms known as phon. The relationship between sone and phon can be expressed by the following formula:

$$\log 10\ \mathrm{S} = 0.03\ (\mathrm{P} - 40)$$

where S denotes the loudness in sones and P denotes the corrected sound level in phons. The sound intensity is measured by instruments such as a Lam Barometer or Sonometer.

SOURCES OF NOISE POLLUTION

Noise may be either natural such as wind, thunder and movement of water or man made. If all symbols of civilization, from jet planes, vehicles, railway engines to factories, generators, construction machinery, television and radio sets and public address systems, have something common—they all produce noise.

Industrial Noise Pollution

The most offending noise sources are compressors, generators, furnaces, looms, grinding mills, releasing valves, etc. that are used in many industrial processes and installed in partially closed or open sheds. A 80–120 dB noise level is common to most units, which is hazardous. Table 6.1 shows the various noise levels in important industries.

Table 6.1: *Noise level in some important industries*

Industry	*Noise level in work area* [dB(A)]
Ceramics glass	90–100
Glass	82–95
Food processing	80–90
Chemicals	85–96
Papers	88–96
Foundry	90–100
Fabrication	82–95
Machinery	85–96
Leather	85–95

Domestic Noise Pollution

Transistors, radio, TV, other musical instruments, air-conditioners, washing machines, kitchen appliances are common sources of noise at home. They not only affect the users but the neighbours too.

Traffic Noise Pollution

Continuous movement of vehicles causes traffic noise. It affects not only those who are moving but those too who live near the roads, railway lines, stations and airports. There has been a gradual increase in the traffic noise in recent years due to increased density of vehicles. According to some estimates, (Singh, 1984), traffic noise level in Delhi is 90 dB and in Mumbai it is 95 dB. Average noise level in Delhi, Mumbai and Kolkata is about 95 dB.

Near the airports, noise levels between 82 dB and 85 dB were recorded with an increase of 20–25 dB during landing and takeoffs.

Near railway tracks too, ambient noise level increases upto 10–20 dB during train movement. Relative noise levels of different vehicles are given in Table 6.2.

Table 6.2: *Relative noise levels of different vehicles*

Type of vehicle	*Noise level (in dB)*
Luxury limousine	77
Small passenger car	79
Miniature passenger car	84
Sports car	91
Motor scooter (I-cylinder 2-stroke)	80
Motor-cycle (2-cylinder 4-stroke)	94

Other Sources of Noise Pollution

In metropolitan cities like Mumbai, Kolkata, Delhi and Chennai, the crowded markets have become great source of noise pollution. Theatres, dance halls, circus carnivals, religious activities, fairs, and festivals are other sources of noise pollution. Aircraft noise pollution is a matter of serious concern, specially in areas close to international airports. Satellite launching operations and atomic explosions emit lot of noise, though for a specific duration.

During last 100 years, there has been substantial increase in noise from man-made sources. According to a survey made by EEC, 48 per cent of population suffers due to traffic noise, 30 per cent faces industrial noise and 2 per cent population bears aircraft noise. Noise levels are known to double in every ten years.

EFFECTS OF NOISE POLLUTION ON MAN

Ambient Air Quality Standards, as prescribed in Environment According to Protection Third Amendment Rules (1989), noise level should lie between 50 to 75 dB during day and 40 to 70 dB during night (Table 6.3).

Table 6.3: *Ambient air quality standards*

Area	Limits in dB (A)	
	Day time	Night time
Industrial area	75	70
Commercial area	65	55
Residential area	55	45
Silent zone	50	40

However, in many industries around the world, workers have to endure sound levels as high as 110 to 115 dB. Sound is uncomfortable beyond 100 dB. Noise levels generally exceed 85 dB in metropolis all over the world. The effects of noise on man are of two types.

Auditory Effects

The first organ to be affected by noise is the ear. More than 40 per cent cobblers, fruitsellers, shopkeepers and drivers complain of tinnitus in the ears. Continuous exposure may lead to deafness/permanent loss of hearing. It is due to complete destruction of the organ of corti that transmits sound from ear to brain. WHO statistics suggest that around 5 per cent of the school children suffer from varying degree of deafness. According to U.S. Public Health Service, more than 7 million people are working where noise levels are high enough to damage hearing. Noise is a major health hazard in industry.

Non-Auditory Effects

Noise promotes the development of several non-auditory health effects including speech disturbances, sleep problem, insomnia, annoyance, hypertension and physiological disorders. These are neurosis, anxiety, insomnia, hypertension, sweating, giddiness, nausea and fatigue. Cardiovascular system is specially vulnerable to high levels of noise. Chronic noise may lead to abortions and congenital defects.

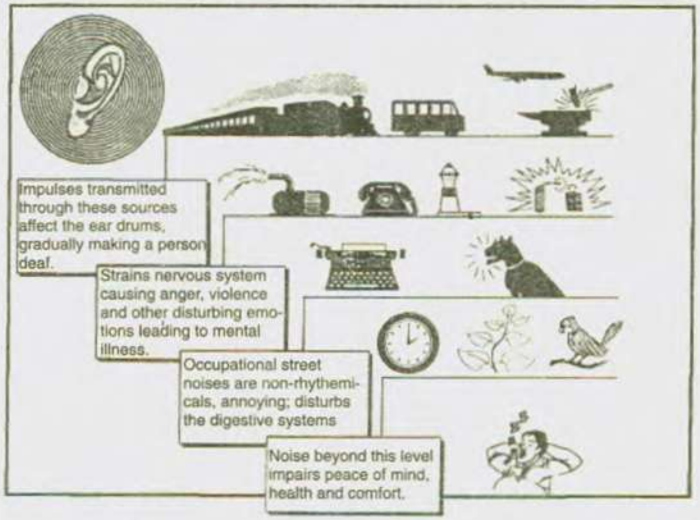

Figure 6.1: *Common noise sources hurting our ears, resulting in physical inactivity*

Reactions to noise pollution could be listed almost endlessly when one hears a loud noise—the blood vessels constrict, the skin pales, the pupils dilate, the eyes close, one winces, holds the breath and the voluntary and involuntary muscles become tense. Gastric secretions diminish and blood pressure increases. Adrenaline is suddenly injected into the bloodstream, which increases tension, nervousness, irritability and anxiety (Figure 6.1). Prolonged exposure to such noise can lead to severe mental disorientation and in some cases, violence. According to Nobel Laureate Robert Koch, *noise is the worst enemy of health.*

EFFECTS OF NOISE POLLUTION ON WILD LIFE

Wild life too has been affected by noise. Health status of several zoo-animals, viz. deers, lions, rhinos is known to be affected by noise. They appear dull and inactive. Several migratory birds have stopped resting in a habitat close to noisy cities. Grizzly bears, musk-oxen and Kangaroo rats in Malaysia have been affected by noise. They leave their habitat and move to calm places. This change in habitat alters their food habits, health and mating behaviour.

CONTROL OF NOISE POLLUTION

Having established that noise does have an impact on human health and well-being, we now turn our attention to controlling noise pollution. It is necessary to analyze the noise, in particular its emission, transmission and immission (Fig. 6.2). Although the best approach is to control the noise at its source, this is not always possible and so solutions must be found further along the path of the noise. Figure 6.3 shows the production of noise and its transmission paths.

When examining a noise source, one must consider whether the noise is due to air turbulence or mechanical vibrations. Noise of the former type is produced by ventilators, jet engines, and the intake and exhaust of combustion engines. This kind of noise can be reduced by decreasing airflow velocities and duct dimension, the use of turning vanes, avoiding lift fluctuations and steadying combustion. Noise generated by mechanical vibrations can be controlled by isolating or damping the vibrations, eliminating their cause, or by reducing the surface area of the vibrating material.

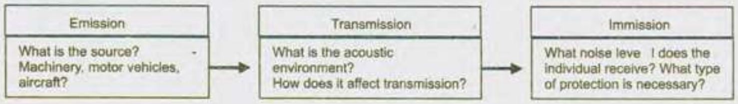

Figure 6.2: *Emission, transmission and immission aspects of noise*

Another method is to change the nature of the vibration including the frequency or force generating the vibration, or the frequency response of the part that vibrates. Such changes can reduce the amplitude of the vibration or shift the frequency of the vibration to a frequency to which humans are less sensitive. With regard to Figure 6.3, the amplitude and frequency spectrum of the force, which is the fundamental cause of the noise, can be modified. Induction and/or damping of the machine structure can be used to weaken the vibration passing from point E to point S. By using the correct shape and material, the external surface, S, will radiate less energy. Finally, insulation material can be placed between the machine and the floor to minimize the transmission of vibrations to the floor, which in turn will start vibrating and radiating noise (p"").

If the noise cannot be completely controlled at the source, the transmission path can be modified by using barriers of sound-absorbing or reflecting material, and/or by choosing the site so as to minimise the received noise level. Whenever possible, the siting of the noise source should receive careful consideration in order to minimise both noise and the cost of installing barriers. The aim should be to maximise the distance between the source and receiver. However, other factors such as the direction of the prevailing wind must also be considered. Siting is particularly important in the management of noise on highways and airports. When noise control through siting is not possible or not completely effective, noise barriers may be necessary. These include fences, screens, or complete enclosures which block the transmission path. Fences are often used along highways and railways. Barriers are usually only partially effective and can be very expensive. In addition, it may not be feasible to use them in enclosed spaces if the machinery needs large amounts of air for cooling or if a combustion process is involved.

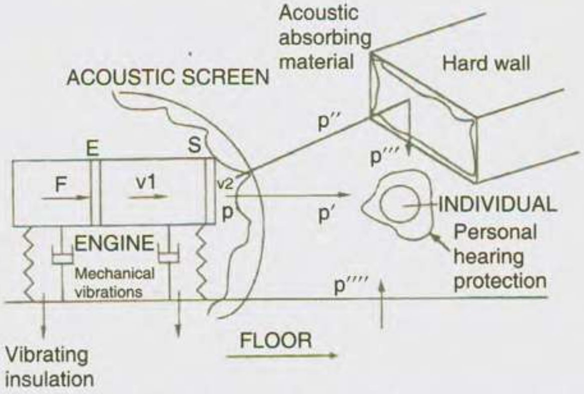

Figure 6.3: *Production of noise through mechanical vibration and its transmission paths. A variable force F (sine, periodic, random or impulse) interacts with the structure of the machine at point E, which starts to vibrate with a velocity VI. The wave propagates and causes an external surface S to vibrate with a velocity V2. This surface will radiate acoustic energy in the form of a sound wave propagating in the air. The sound pressure p will possibly be weakened to value p' before it reaches the human ear. There is also the possibility that wave p", after reflection on a wall will reach the individual with the sound pressure p"'. The individual hears p' and p"'. The machine also causes the floor to vibrate, which in turn radiates sound p""'.*

Absorption of sound through the use of acoustical absorbing materials is one of the most effective ways of attenuating sound in the transmission path. These materials can be in the form of carpets or tiles. However, it is not effective for direct sound.

Table *6.4: Average values of the attenuation of personal hearing protection (the standard deviation (0") is indicated between brackets)*

Type of protection	125 Hz	250 Hz	500 Hz	1,000 Hz	2,000 Hz	4,000 Hz	8,000 Hz
Dry cotton wool plugs	2	3	4	8	12	12	9
	(2)	(2)	(3)	(3)	(6)	(4)	(5)
Waxed cotton wool plugs	6	10	12	16	27	32	26
	(7)	(9)	(9)	(8)	(II)	(9)	(9)
Glass wool plugs	7	II	13	17	29	35	31
	(4)	(5)	(4)	(7)	(6)	(7)	(8)
Personalised ear-mould plugs	15	15	16	17	30	41	28
	(7)	(8)	(5)	(5)	(5)	(5)	(7)
V-5 I R type plugs	21	21	22	37	32	32	33
	(7)	(9)	(9)	(7)	(5)	(8)	(9)
Foam-seal muffs	8	14	24	34	36	43	31
	(6)	(5)	(6)	(8)	(7)	(8)	(8)
Fluid-seal muffs	13	20	33	35	38	47	41
	(6)	(6)	(6)	(6)	(7)	(8)	(8)
Muffs and safety helmet	14	17	29	32	48	59	54
	(4)	(5)	(4)	(5)	(7)	(9)	(9)

Source: May, 1978

The final option in noise control is to protect the receiver through the use of personal hearing protection and by limiting exposure time. Personal hearing protection includes full and semi-insert earplugs, earmuffs or noise helmets. Table 6.4 shows the effectiveness of different types.

Full-insert earplugs have the advantage of not requiring any external support, unlike semi-insert earplugs, and thus do not interfere with head covers, masks or goggles. Earmuffs provide better protection, particularly at the higher frequencies, but their effectiveness depends on the materials used. 'Sound proof' helmets increase protection at the higher end of the frequency spectrum, but they are not commonly used for hearing protection alone and combine this function with protection against head injury or low temperatures.

It is important that individual hearing protection be comfortable, well-fitted and properly maintained, otherwise the degree of protection may be decreased. Regular checks should be made to ensure that employees are wearing their protection devices.

STUDY QUESTIONS

1. Describe different sources of noise pollution.
2. Describe effects of noise pollution on man.
3. Give an account of noise pollution control methods.
4. Write short notes on the following:
   (a) Units to measure noise pollution
   (b) Traffic noise pollution
   (c) Effects of noise pollution and wild life

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