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Environmental Science

CENTRE FOR DISTANCE AND ONLINE EDUCATION

ENVIRONMENTAL SCIENCE

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Unit 01: Multidisciplinary nature of environmental studies, Scope and importance

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Summary

Key words

Self assessment

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Objectives:

After careful study of this chapter you will be able to

- know what the environment is.
- how is Environmental Studies a multidisciplinary subject?
- understand meanings of various terms related to environmental studies.
- know the scope and importance of environmental studies.
- define sustainable development.
- understand the need of sustainable development for our survival.
- know the importance of land resources.
- understand the structure and function of soil.
- learn causes of land degradation.

Introduction:

In the first unit of the subject Environmental Studies, we would first discuss what is environment and how the study of environment is important for our personal and professional well being. India and many developing countries are suffering from population rise and consequent problems like lack of employment, intra-generation inequality, rising environmental pollution etc. Much of these problems are caused by the current economic model and inefficient technologies used for industrial and commercial activities, which also leads to unsustainability i.e. current economic model could not be supported by resources available on our Earth. The second topic of the unit is sustainable

development. We would learn about best economic models to provide standard living conditions including a healthy environment to each and every citizen of our Earth. After that we would discuss natural resources, on which whole of our economy and survival is dependent. In this unit we would only talk about land resources. Discussion of other natural resources is the part of unit 2 and 3. Our discussion of natural resources is focused on how we are dependent on them and what problems are associated with their utilization.

1.1 What is Environment?

Everything which surrounds us is our environment. It is the sum total social, economical, biological, physical, chemical factors which constitute the surrounding of a person. So the climate of the region in which we are living, its soil, plants, animals, governance, education system, social customs, baking system etc. all make our environment.

1.2 What is Environmental Studies?

Environmental Studies as the name suggests deals with every issue which affects human well being. It is a multidisciplinary subject which tries to find solutions to current problems related to the environment. These are sustainable development (i.e. how human civilization can sustain with Earth's limited resources), health, how to provide standard living conditions to every human, what is the importance of various components and processes of the Earth System etc.

1.3 Multidisciplinary nature of Environmental Studies

Environmental Studies or study of the environment needs help of biology, chemistry, physics, sociology, economics, computer science, engineering, health sciences, anthropology and philosophy.

The chemistry or environmental chemistry is essential as it provides the fate of a chemical compound in the environment and how they change the chemistry of atmosphere, water, soil etc. Health Science especially toxicology tells us the impact of newly entered substances on human health. It also tells us the minimum concentration of the compound in water, air, soil and food which could be harmful to us. Physics, especially atmospheric and geophysics are important to understand our environment. Atmospheric physics tells us how global warming and loss of forest cover is changing our climate. Geophysics informs us movement of tectonic plates and processes which generate various land forms.

Biology specially its branch ecology which tells how various species are connected to each other and are important in the functioning of natural ecosystems. Most of the services which we derive from the environment are actually services generated from functioning ecosystems.

Engineering especially civil, mechanical and electronics engineering are important for providing practical solutions to maintain air and water quality. It also provides practical solutions for treatment of wastewater, management of solid waste and hazardous waste etc. Computer science is needed to model the climate system, prediction of air quality, modeling of the whole ecosystem and analysis of big data to maintain the health of the environment.

Environmental Studies also need help from social sciences. Economics, especially ecological economics, try to find an answer to how we can assign price tags to various ecosystem services provided to us free of cost. This way we can do a cost benefit analysis for any big infrastructure or other project in terms of its impact on the environment. Sociology and philosophy is also essential in environmental studies as it explains how social injustice (intragenerational and intergenerational equity) leads to environmental degradation. Anthropology, especially ecological anthropology deals with how human culture is adapted to available environmental resources.

1.4 Importance of Environmental Studies

The question is why we should study this subject. The subject is important because it deals with global problems. We are suffering from extreme weather events due to climate change, rise in UV index of sunlight (due to ozone layer depletion), a very fast rate of biodiversity loss etc. Climate change is directly associated with our economy and health. Questions like why the pleasing climate of our country is changing and how we could stop irreversible change in our climate are considered in Environmental Studies. Similarly what is the importance of various species of plant, animal and microbes for us and how we can conserve our rich biodiversity while maintaining growth of our economy to provide standard living conditions to every person of our Earth, are part of the subject.

Now you may think why I should worry about global problems, but still the subject is important because it deals with our local problems. You may be irritated with rising solid waste in the streets

of your city, or high pollution in a river or lake which is part of your city or air pollution from nearby industrial units. You can also suffer from the spread of a new epidemic. The questions like how can we maintain a healthy environment or how the emergence of epidemics are linked with environmental degradation are part of the subject.

Now you may also negate that I am not concerned with above local problems, but still you should study the subject as it deals with your individual problems. We are aware now that tap water supplied by municipalities is not safe for drinking most of the time. Fresh fruits and vegetables we eat contain pesticide residues. Long spells of poor air quality may be affecting your health. The Environmental Studies discuss how we can provide clean, safe and sufficient water to each individual at affordable prices, how we can replace toxic biocides with environmentally benign agricultural methods. The subject also discusses the question of equitable distribution of Earth's natural resources so every human on Earth can live a healthy and fulfilled life.

The dwindling natural resources also require that every person should know about sustainable lifestyle. The following task would explain to you how our life is dependent on natural resources provided by our environment.

Take any article used by you in daily life. Draw a flowchart explaining its journey from natural resources to your home. Now take any of the natural resource used in manufacturing of your chosen article and answer the following questions:

- Is your use of natural resources unsustainable?
- What can you do to reduce, reuse and recycle that resource?
- Is the resource equally available to all of your fellow citizens?

1.5 Scope of Environmental Studies:

Our life and economy depends on vital support provided by our environment. We should try as much as possible to preserve this vital support. A lot of new professions have emerged where expertise in environmental studies is essential. These are mentioned below.

Environment, health, and safety (EHS) professionals:

Now every manufacturing plant and big laboratories needs the services of EHS experts. They (especially Environmental Engineers) are responsible for management of effluent treatment plants, scrubber systems used to clean exhaust gases and health of workers involved in manufacturing or working in laboratories. They are also the contact persons to deal with regulatory agencies.

Environmental journalist and green marketing experts:

To resolve our current environmental problems we need favorable public policies and their effective implementation. This could be possible if we can create public awareness about the value of our natural ecosystems and how our current technologies, and our economic and social practices decrease the availability of these services. Resolution of environmental problems is not just the responsibility of the government, but each citizen of our Earth is responsible to resolve these problems. Only an aware public can force government and businesses to enforce sound environmental practices. This needs the services of environmental journalists which can explain the importance of our environment and related issues of environmental degradation as per the social and educational background of the local population.

The awareness of protection and conservation of the environment is also creating the demand for green products. Green products as recognized by eco-mark in our country are products which are manufactured with minimum impact on the environment. Now many consumer goods companies are also marketing their products mentioning their manufacturing practice, recyclability etc, which needs experts in green marketing.

Restoration and conservation ecologist:

The services of conservation ecologists are required to conserve endangered species in situ and restoration of degraded ecosystems. The workable solution for our conservation problems can only be provided by good expertise in environmental studies.

Research and development:

To find the actual cause of our environmental problems like decline of air quality, impact of climate change, rise of extreme weather events, and development of green technologies for energy, construction, mining, manufacturing etc. needs a lot of research and development. The environmental studies provide a global view of what is ideally required in a given filed.

Did you know?

Data science and artificial intelligence has become a one of the highly utilized tool in Environmental Studies. It is used in analyzing remote sensing data, genomic functions, climate and ecosystem modeling etc. The analyses are helping in formulating economic and environmental policies of governments and business strategies of corporate.

1.6 Sustainable development:

Sustainable development is meeting the needs of our present generation without compromising the needs of future generations to meet their own needs. It was first defined in 1987 by UN's World Commission on Environment and Development.

Need for sustainable development:

Sustainable development concept was originated through our realization that environment and development are interrelated and the Earth cannot supply resources used and wasted by rich members of society and used for sustenance by the ever growing population of the world. Further, the environmental degradation caused by globalization of the economy is forced to move towards sustainable development.

Globalization of the economy has raised the living status of many people around the world. For example, we may take the case of Chinese economy which after opening to international trade was able to create 100-150 million strong middle class and pulled up 400 million people above the poverty line. [Ref. 1]

People in developing countries are now enjoying better access to world class products and health services due to globalization. However, globalization of the economy has also increased the fast consumption of natural resources which led to decline of forest cover, environmental pollution, rise of average global temperature and sea level, and loss of biodiversity. Due to close connection between environment and economy it is now clear that "business as usual" with current technologies is not sustainable. For sustainable development we need a differ type of economy that is termed "Green Economy". Before understanding the green economy let's first discuss classical economic models.

Classical economics:

As per the classical economics economy is the *system of exchange of goods and services between members of society developed by society itself*. Classical economics consider **land**, **labor** and **capital** as three factors of production and involve circular flow of money between businesses and households as shown in Fig. 1.

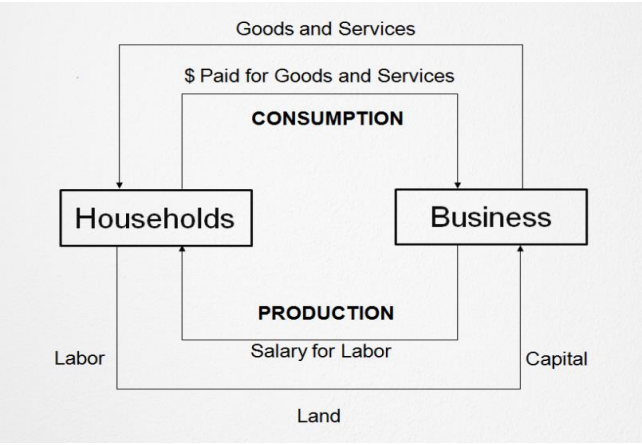


Figure1. Classical view of economic activity. (Source: Ref. 2)

As shown in Fig. 1, money flows in a circular manner in the economy as households pay the price for goods and services provided by businesses and businesses pay salary to working members of households. In classical economics land represents all natural resources available on Earth. There are two main types of economic systems currently prevalent in our world: (1) Centrally planned economy, (2) Capitalist (free market) economy.

Centrally planned economy

In centrally planned economies, rulers decide what should be produced including its quantity and who would be employed for manufacturing. Most of the manufacturing and service organizations are owned by the government and workers have no freedom to change or choose their professions. This type of system was prevalent in former Soviet Union nations (USSR), Mainland China and some Asian countries. This economic system generated a lot of chaos in former Soviet nations which resulted in the collapse of the USSR.

Free market (capitalist) economy

In the free market economy the market itself decides what to produce, how much to produce and whom to be employed and at what salary. In a free market economy the government has less interference in all of these economic activities. Any person or group of persons could establish its business to provide goods or service as per market demand. Free market economy inspires competition and provides access to consumer best quality products or services at reasonable prices. The prices and salary of labor or workers are decided by principal of supply and demand. But, this economic system *lacks conscience*.

If there is a population rise and a lot of young people are there to find job, then businesses reduce their salary resulting in exploitation of workers. Capitalist economy only provides access to goods and services, if people of a country do not have money to pay for it, then they won't invest in skilling in these persons so they can be gainfully employed and acquire some income, as this won't provide them immediate profit. Also some one player of the free market economy may try to take monopoly over the market by unethical practices, and then all benefits of the free market economy are lost. Further, in the classical economy all natural resources are considered as land. Businesses can use them as much possible as they can to amass maximum wealth. To maximize profits businesses can also avoid the cost of implementing pollution control measures, and can degrade the environment.

Ecological economics: The way to sustainable development

To address the negative impacts of capitalism and associated globalization, a type of economics is recently developed which is called ecological economics. Classical economics mainly concerned about how to enhance profit of organization and GDP of a country. However, in ecological economics the main concern is how to improve human well being. The economic system which is promoted by ecological economics is termed *Green Economy*. Green economy inherently involves sustainability.

Natural resources and Ecological Economics

In classical economics the three factors of productions are land, labor and capital, where all the natural resources and ecosystems containing them, are part of land. To generate more wealth we can utilize as much natural resources as we want. Classic economic views consider the environment as a set of resources within the larger sphere of human economy. Ecological economics is opposed to this view of classical economics. As per ecological economics, the human economy is part of the environment which depends on resources provided by the environment and its capacity to absorb waste generated by human activities. Without the availability of natural resources provided by the environment and its ability to break down pollutants generated by human activities, no economy can exist. Ecosystems and natural resources found in a given country provide the basis for the economy of that country. Similarly, the whole biosphere provides the basis for the global economy.

In ecological economics, economic production is viewed as conversion of the natural world to manufactured world. For example, soil which is a natural resource is converted to cement then to concrete structures or sand and other minerals converted to electronic gadgets. Human economy is a part of the enfolding ecosystem and depends on natural resources flowing in it, which are converted to manufactured goods with the help of labor and capital (energy is part of natural resources). These transformed resources re-enter the ecosystem in the form of waste after ends of life of manufactured goods (Fig. 2).

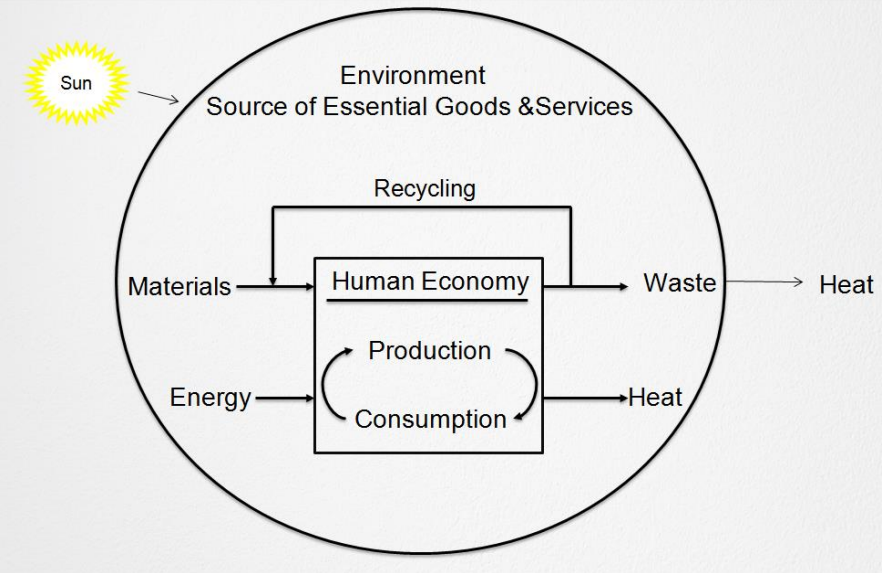


Figure2. Ecological economics view of human economy. (Source: Ref. 2)

As the human economy expands, the natural world shrinks. In time, equilibrium should be reached because if the natural ecosystems collapsed the supply of vital natural resources and services provided by them would also be stopped.

Natural ecosystems and mineral resources which are the part of a country constitute its *natural capital*. Ecological economics advocates about natural capitalism in contrast to conventional capitalism, where the role of natural ecosystems and their sustainability is of central one. Other components of wealth of a nation as measured by the World Bank are produced capital and intangible capital which are discussed below.

As per the classical economics economy is the *system of exchange of goods and services between members of society developed by society itself*. Classical economics consider **land**, **labor** and **capital** as three factors of production and involve circular flow of money between businesses and households as shown in Fig. 1.

What constitutes the wealth of a Nation?

Ecological economics is concerned with environmentally sustainable development to increase human well-being with time. It studies how to manage all assets available with society to increase human well-being. The assets available with society or with the nation (also called nation's wealth) are produced capital, natural capital, and intangible capital.

Produced capital is all man-made capital goods needed for production of goods and services. This includes manufacturing plants, buildings and infrastructures, monetary savings and stokes, transportation system etc. Produced capital is directly linked with how much income a nation can generate. Assets of produced capital also suffer from wearing and aging, which is called capital depreciation of capital consumption. Both income and depletion are linked with produced capital.

Natural capital constitutes natural ecosystems and mineral deposits of a country. Natural capital consists of some indispensable resources for our economy like fresh water, soil, solar energy, timber, fishes etc. Natural capital also provides us many services like climate regulation, waste breakdown, oxygen production etc. There are two types of natural capital: renewable and nonrenewable. Renewable natural capital (forest, water, fishes etc.) is subject to depreciation but could provide us sustainable income it used wisely. Nonrenewable natural capital (like crude oil, coal, iron ore etc.) does not have this capacity.

Intangible capital consists of three components: human capital, social capital and knowledge asset. Human capital refers to citizens of a country and their physical health, psychological health, IQ level etc. Education is another attribute of human capital which provides them skills useful to be a player in the economy of the country.

Social capital of a nation constitutes formal institutes run by the government, civil liberty, protection of human fundamental rights, court system, social inclusiveness etc. It is a vital component of nations' wealth as it affects and gets affected by economic processes.

Knowledge assets of a nation are written or codified knowledge, technology which can be transferred readily between generations and to any part of a country. Knowledge assets help nations to convert available natural resources to useful products needed by their citizens. It grows constantly and needs enough libraries, universities, schools and IT infrastructure so citizens can have access to it.

The World Bank's Environment Department has devised various methods to measure the wealth of nations. A measurement of wealth by the World Bank provided some interesting facts. There is notable difference between per capita wealth between nations. Major component of wealth of many nations is intangible capital. Per capita wealth grows by 17% in a 10-year study period. Mostly this growth is caused by increase in intangible capital (social and human capital) and it was due to investment in education, health, and nutrition by nations.

Measurement of true economic progress

In classical economics growth of a nation is measured by rise in GDP (gross domestic product). GDP is the total cost of all goods and services produced by a country in a given time period. It does not include income coming from non-resident citizens living abroad. GDP per capita is used to compare rich and poor countries and to measure economic progress of a country. In GDP calculation the depreciation of assets used in production is also considered. The depreciation of produced capital is charged against the value of production. The depreciation of produced capital is routinely subtracted from the value of goods or service generated with the produced capital in calculation of net GDP.

There are many flaws in the calculation of GDP. It does not include goods created and services performed by family for itself. So, the subsistence farming done by tribal and rural communities in developing countries is not included. Similarly, the important works done by housewives in their homes are omitted in calculation of GDP. The GDP also excludes values of services provided by natural ecosystems. For example, clean air has the same value as medicine for asthmatics, but in GDP calculation only the value of anti-asthmatic drugs is included, not the value of clean air generated by natural ecosystems.

Natural capital depreciation. Classical economics does not include depreciation of natural capital in calculation of GDP as pointed out by ecological economists. In classical economics, for example, the cost of all timber obtained by cutting down a whole forest is included on the income side while in capital depreciation, only depreciation of mill saw trucks would be included to calculate net GDP. Cost of all ecosystem services which are lost is not accounted for in calculation of net GDP. This is the cause of that nations tries to increase their GDP by extensive farming and then suffers from loss of soil fertility, by removing forest and then suffers from extreme weather events and biodiversity loss, by allowing overgrazing and then suffering from desertification. A more accurate net GDP calculation should consider all these depreciation of natural capital into account.

Genuine progress indicator. The inability of GDP to measure true economic progress, inspired development of another index called Genuine Progress Indicator (GPI). It was first proposed by nonprofit organization Redefining Progress. In GPI calculation some kinds of economic activities are considered positive and sustainable, and others are considered negative, even if they are used in calculation of GDP. Some of the positive economic activities are not included in calculation of GDP such as labor that goes in housekeeping, parenting. The negative factors which are included in GPI calculation are: cost of crime, loss of leisure time, cost of pollution, deletion of nonrenewable resources and loss of fertile land. A calculation of the GPI of the United States in 2004 found positive contributions at $11.06 trillion, while the negative contributions were $4.42 trillion giving net GPI $4.42 trillion. In comparison to 2004 net GPI, net GDP of the same year was $11.71 trillion. An analysis of 1950 to 2004 GPI and GDP of the US is shown in Fig. 3. It is clear from the figure that though GDP of the US is increasing continuously, but GPI is almost constant, which implies that current economic model is also increasing negative contribution to GDP.

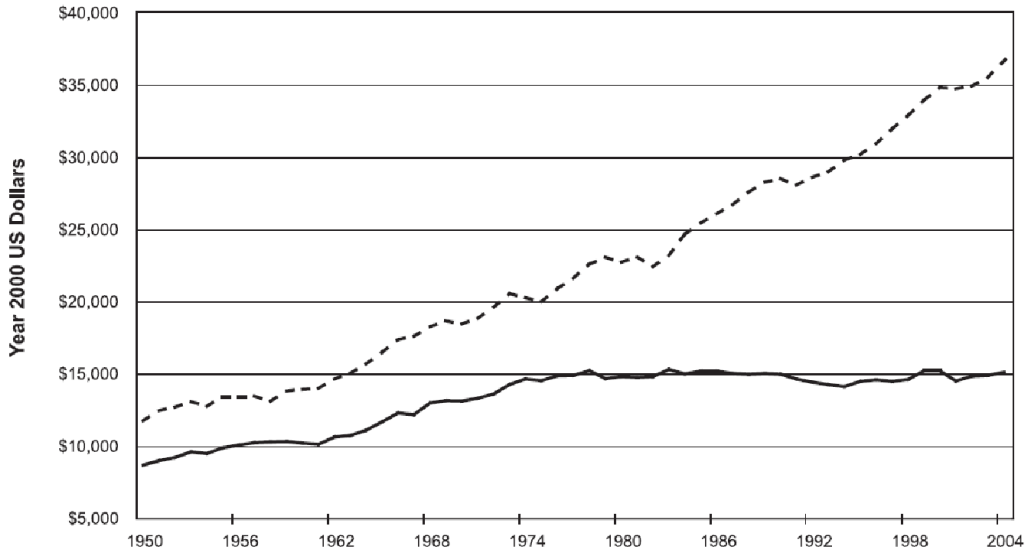


Figure3. GDP and GPI per capita, 1950-2004 (in year 2000 dollars). (Source: Ref. 3)

Resource distribution in Green Economy

There is a great difference in the distribution of world's wealth around nations. This is mainly caused due to difference in human resource dominated intangible capital and produced capital. Thus, it is required to focus on economic development which fosters growth in human resource and produced capital, if we want more equity in distribution of resources among nations.

Intragenerational equity. What are the reasons that some countries have undergone rapid development and others have not? Population growth is one of the reasons. Possibly, the most important reasons are related to major institutions which coordinate social and political life of a nation and are part of its social capital. Social capital of a nation is characterized by its implementation of human fundamental rights, social inclusiveness, and a well-developed market economy in which entry and exit from a market is free for businesses and people. It also includes an honest legal system, free press and broad civic participation as they are essential to protect the fundamental right of citizens. A robust financial market and communication and transportation network are also essential for a free market economy.

As evident from the history of the world, if all the above-mentioned resources are in place, a society can make rapid progress in development of human resource and produced capital. If it lacks above resources then corruption, inefficiency, banditry, injustice and intolerance often prevail with the outcome of continuing poverty and environmental degradation. There are many parameters which can measure social capital of a nation such as rule of law index, index of civil liberty etc.

Intergeneration equity. Intragenerational equity is characterized by "golden rule" of *making possible for others what is possible for you*. Sustainable development also talks about intergenerational equity.

Intergenerational equity means whatever natural capital we have, that should also be available to our future generation. There are a lot of confrontations between benefits of a developmental project to current generation and supply of uninterrupted ecosystem services to our future generation which may decline due to the proposed developmental project. It has been argued that conserving resources for future generation or sustainable use of resources may deprive current generation especially poor to improve their livelihood.

Above argument looks legitimate, but it has been observed that given the choice a large proportion of people want to see their children and grandchildren to live a better life than what they currently have. They are ready to sacrifice in order for a great future ahead. Sustainable development is economic progress which can improve the living condition of the poor and underprivileged under the carrying capacity of the biosphere of our Earth or how can we sustain with interest natural capital without depreciating it.

1.7 Natural Resources

Our economy and survival on Earth is dependent on natural resources provided by the environment. After understanding what sustainable development is, let's discuss in detail how we are dependent on natural resources and what are the current problems associated with unsustainable use of natural resources.

There are two types of natural resources: renewable and non-renewable. Many renewable resources like water, clean air, soil, food are provided to us as ecosystem services of natural and man-made ecosystems. Renewable resources are either replenished spontaneously or are inexhaustible like sunlight, wind etc. Replenishment of renewable resources depends on equilibrium between rate of recharge and rate consumption. The rate of recharge of renewable resources depends on natural cycles such as water cycles. High extraction rate of natural resources can even lead to collapse of replenishment of natural resources. Fossil fuel and mineral resources are nonrenewable resources available in our environment. Let's first discuss land resources.

1.8 Land Resources

Land is an important finite resource of a country that is used for creating housing complexes, agriculture, establishing industries, communication and transportation infrastructure and pastureland by humans. You can understand the importance of land, by asking the price of land in your locality. We also need to protect land supporting wilderness areas of forest, grassland, wetland, coast, mountains to supply vital ecosystem services. Rising human population is creating conflict between the use of land for the human economy and protection of land for vital ecosystems. We need to plan a rational use of land, so maximum human welfare is ensured (Fig. 4.).

Land is a solid portion of earth crust, one of the three concentric layers of our Earth (other layers are mantle and core). Land is also available on Moon and Marsh, but this is not so useful for us, similarly many of the deserts of our Earth are sparsely habituated by humans. It is the presence of soil over land which makes it useful for us. Soil is the foundation for all terrestrial ecosystems which provide all renewable resources essential to us. Desert land and land of other planets does not have fertile soil.

Even if availability of fertile land is limited, we are suffering from land degradation. Before understanding why our important resource is degrading, let's first understand the structure and function of soil.

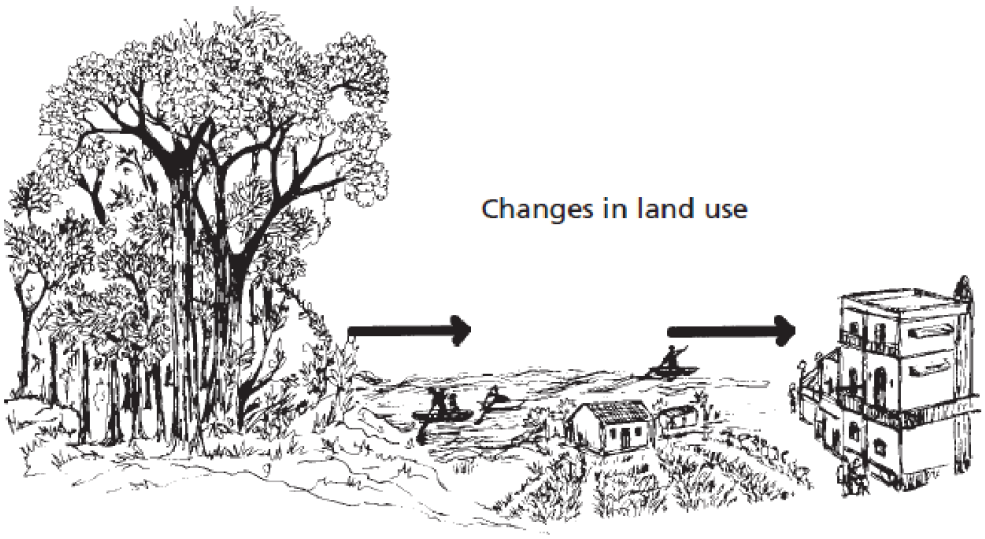


Figure 4. Land and its uses (Ref. 4)

1.9 Structure and function of soil

Soil is an important component of land, which makes land habitable to humans and makes it important to all other applications. Let's discuss the structure and function of soil.

Structure of soil

Soil is a living community and made of many layers supported over bedrock. It is made of many layers (Fig. 5).

O-layer: The topmost layer of soil is called O-layer. O stands for organic matter, as this layer is made of leaf litters and detritus generated by plants and animals. It is found at 0-2 feet of depth. It contains both un-decomposed and decomposed organic matter in the form of humus. Upper O-layer (Oi) is rich in un-decomposed organic matter, while lower O-layer (Oa) is rich in humus.

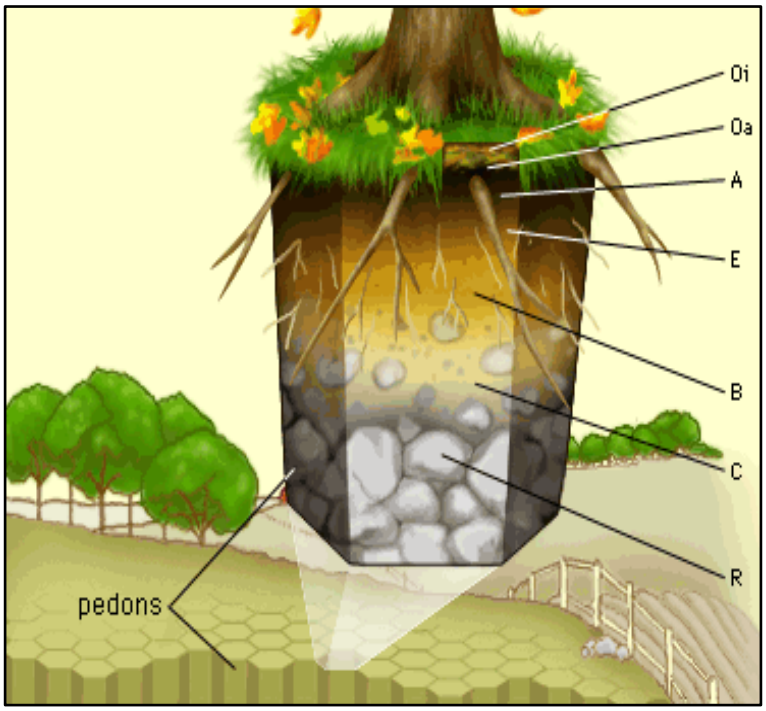


Figure 5. Soil profile.

A-layer: This layer is found just below the O-layer at depth of 2-10 feet. It is also called topsoil. It is a mixture of humus from O-layer and mineral soil from below the A-layer. Due to comparatively high content of humus it is darker in color than B- and C-layers. A-layer is also the habitat of soil organisms and due to this it is also called Biomantle.

The soil organisms (for example: earthworm, termites, nematodes, millipede, ants, fungi, soil bacteria and soil protozoa etc.) are part of the detritus food web. They help in releasing nutrients trapped in detritus back to soil. The undigested part of detritus mostly forms the humus. Humus is very important in maintaining soil fertility as it has very high capacity to hold water, works as an adhesive which provides soil optimum texture for aeration of roots and is rich in nutrients. Humus is ultimately degraded material whose further degradation is very slow. Humus slowly converts, at rate 2-5% of its volume, to mineral a process called mineralization. It takes 100 year for formation of one inch layer of topsoil.

E-layer: The next layer below A-layer is E-layer and found at 10-15 feet of depth. Here *E*- stands for eluviations (process of leaching), as nutrients get dissolved away due to downward movement of water. It is lighter in color than the two layers above it.

B-layer: Below E-layer is B-layer and found at 10-30 feet of depth. It is also called subsoil and contains minerals leached from A- and E- layers of soil. Plant roots extend this horizon and moisture level in soil should be at least till B-horizon. Subsoil is high in clay and possesses reddish or yellow color due to presence of oxides of metal.

C-layer: This layer is found below B-layer and mainly consists of broken parent rock like gravel, boulders etc. It is found at 30-48 feet of depth and devoid of any organic matter. Its composition and structure tells us geological processes that created the landscape. The C-layer is least affected by biological and chemical processes going on in layers above it.

R-layer: R-layer or rock horizon is the deepest layer of soil and found at 48+ feet of depth. In comparison to C-layer it is made of continuous mass of solid parent bedrock. Its color depends on mineral composition of rock.

Did you Know?

37 Tons of soil per hectare passes per year through the gut of earthworms. After passing through the gut of earthworm, soil particles are glued together by indigestible humus in stable clumps or castings, which is important for fertile soil.

Functions of soil

In agriculture: Soil is important to support plant growth. It provides plant essential nutrients, water and air to its roots. Soil also provides physical support to plant through its root. The A-layer of soil is very important for plant growth as it holds nutrients and water.

Role in nutrient cycle: A fertile soil is a renewable resource as whatever nutrient absorbed by plants is regenerated in soil again from detritus. Soil is a living entity and home of many soil organisms found in A-layer of soil. These organisms form a detritus food web and convert detritus back to humus. In this way nutrients trapped in dead animals, plant bodies and bio waste are released back in soil.

Regulate the water: Soil just not only provides water to plants but a healthy soil also absorbs a lot of water and slowly recharge underground aquifers. In this way it also mitigates flood disaster in event of heavy rainfall.

Purification of groundwater*:* A healthy soil possesses negatively charged organic matter consisting of high molar mass humic fractions. These components of soil adsorb many heavy metals entered in rain water from landfill and other contaminated sites. In many sacred groves the groundwater is so pure that it does not require any further treatment. [Ref. 5]

Producing clay: Clay is an important raw material used in manufacture of cement, bricks, earthen wares and ceramics. A fertile soil can regenerate clay taken away in mining operations through the mineralization of humus.

Carbon sequestration: Due to slow decomposition of organic carbon present in detritus, soils holds as much as three times more carbon than present in the atmosphere and live plants. Decomposition soil organic matter back to CO_2 depends on many factors like temperature, moisture, physical separation of soil particles and separation between plant roots. It is observed that degradation of ecosystems supported by soil disturb dynamics of soil organic matter decomposition and net carbon is released in the atmosphere in comparison to intact ecosystems.

1.10 Land degradation

After learning the importance of soil in making land useful for humans, let's discuss what is causing degradation of land. The two main causes of land degradation are soil erosion and desertification.

Soil erosion

The removal of top soil by water and wind is known as soil erosion. Whenever soil is left bare, it becomes vulnerable to soil erosion. There are three types of soil erosion: splash, sheet and gully erosion. **Splash erosion** occurs when bare soil is exposed to heavy rainfall. The falling water droplets break down clumpy structure of soil and dislodged particles of soil carry away with water in space present between soil aggregates of clumpy soil structure. This reduces infiltration and aeration of soil. Reduction of infiltration leads to more water flow through the surface of soil which leads to **sheet erosion** i.e. removal of fine particles from the surface of soil.

When water converges in stream and rivulet which have greater volume and velocity, then it leads to **gully erosion**. The gully is a more severe type of erosion. The three major causes of soil erosion are: Overcultivation, overgrazing and deforestation.

Overcultivation. Plowing is an important first step in agricultural production. It improves aeration, infiltration of soil and removes weeds, so help in freshly sowed seeds and saplings. However, the same operation makes soil exposed to air and water erosion due removal of vegetative cover. It also accelerated evaporation from soil. The intensive agriculture (harvest of more one cash crop in a year) and lack of crop rotation further add to the problem of soil erosion.

Use of inorganic fertilizers during intensive agriculture (needed to fulfill large nutrients demand) also caused land degradation. Inorganic fertilizers, unlike organic compost, lack of humus and organic matter. It reduces soil's water and nutrient holding capacity as formation of humus by soil organisms is stopped due to lack of food in form of organic matter. Lack of humus makes the soil particles loosen and causes more erosion.

Overgrazing. Grasslands with very little rainfall cannot support cannot support cultivation of crops. These grasslands are normally for grazing of cattle, sheep, goats etc. Approximately, 65% of dryland of the world is actually rangeland or pastures. When the grassland is unable to keep up with overconsumption caused by livestock, then it leads to soil erosion. Overgrazing also leads to destruction of grasslands and causes loss of biodiversity.

Deforestation. Forest helps in generation and protection of humus rich topsoil. The rich cover of leaf litter and detritus also help in reduction of evaporative loss of soil moisture. However, when forest is cut down then exposed topsoil is removed easily by water and wind erosion. Since generation of soil is a very slow process (at best one inch per 100 years), loss of topsoil results in decline of land productivity or land degradation.

Desertification

Decline of primary productivity and agricultural production of semi arid and arid regions (drylands) is called desertification. Desertification does not mean advancement of the desert, but it is a process of land degradation caused by mostly human activities. Many possible causes of desertification are long spells of drought, overgrazing, deforestation, overcultivation, salinization and mining activity.

Drylands mostly support grassland ecosystems due to presence of good water and nutrient holding capacity of soils of drylands. Erosion of topsoil (A-layer) of these drylands by overgrazing, deforestation, overcultivation or mining activity, leads to desertification of semi arid and arid regions.

Overgrazing or deforestation stops generation of humus in topsoil which is a very important adhesive bonding soil particles creating soil aggregates with good infiltration and water absorption capacity. Further, conversion of existing humus to mineral makes soil particles (clay, silt, sand) to be loosened. The light soil particles are easily carried away by wind (causing dust storms) leaving behind only sand which is the characteristic of desert soil.

Intensive irrigation is also one of the causes of desertification. The intensive irrigation through the canal or using groundwater lead to water logging (saturation of soil with water till root zone) and as the temperature of dryland is high, it results in fast evaporation of surface moisture of soil leaving soluble mineral in the topsoil. When salt concentration in topsoil becomes too high (called salinization) that plant cannot absorb soil water or get desiccated, then it leads to desertification.

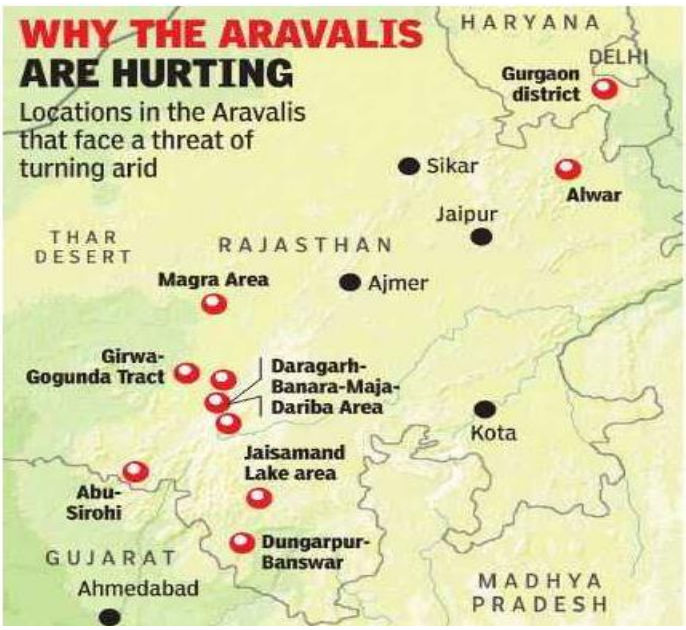
Dryland occupies some 6 billion hectares of Earth and is home to 2 billion of the world's population. About 10-20 percent of these lands are suffering from the problem of desertification.

Desertification of Aravalis

Aravali mountain range supports many thorny forests interspersed with stony range. It is a life line for Delhi-NCR as it recharges groundwater, protects it from advancing desert through stopping sand storms and improves air quality. Severe deforestation and mining activity have reduced perennial river areas by 33% and non-perennial river areas by 97% in Aravali hills. It also added 5 km^2 more barren land. Most dangerous is the decline of thorny forest which works as a barrier for dust storms towards Delhi. Decline of ability of Aravalis ecosystem services may cause desertification in NCR, western UP and Haryana.

(A)

(B)


WHY THE ARAVALIS ARE HURTING
Locations in the Aravalis that face a threat of turning arid
HARYANA
DELHI
Gurgaon district
Sikar
Alwar
Jaipur
THAR DESERT
RAJASTHAN
Magra Area
Ajmer
Girwa-Gogunda Tract
Daragarh-Banara-Maja-Dariba Area
Kota
Jaisamand Lake area
Abu-Sirohi
Dungarpur-Banswar
GUJARAT
Ahmedabad
MADHYA PRADESH

(C)

Figure6. (A) Gap forest of Aravali hills, (B) Impact of dust storm (Source: Down to Earth) (C) Areas of Aravalis which are facing threat of land degradation (Source: TOI, Ref. 6)

1.11 Soil Conservation

No-till farming

In no-till farming weeds in agricultural fields are not killed by plowing it before planting seeds, but by herbicides. Then a special apparatus run by tractor is used to do many operations at one time. It creates a furrow through mulch covered soil, drops seed and fertilizer and then closes it. In the process soil is not left exposed to be eroded by wind and water, thus this technique allows multiple harvests without causing soil erosion. This technique maintains detritus and stops evaporative loss of moisture from soil.

Contour farming

This is a technique to cut down soil erosion in sloping lands. In this technique plowing is done at the right angle to contour slope, instead of along the slop. Terracing is another version of contour farming which is utilized in still steeper slopes. It includes broad terraces run across a contour. Terracing provides enough water for crops and reduces soil erosion.

Strip cropping

In strip cropping, a strip of crop alternates with a strip of soil conserving and humus forming grasses and grass legume mixture. Soil which is eroded from the crop strip is retained by strips of undisturbed grasses. Further, leguminous plants also fix nitrogen in soil.

Agroforestry

Agroforestry is an ecologically based dynamical natural resource management for agricultural production. It involves integration of trees (major vegetation of forest) on a farm. It is a multi-disciplinary approach which needs expertise of agronomist, animal care specialist, forester, landscape planner, economist, soil analyst and others to mimic self-sustainability and high productivity of forest ecosystems. It is a part of the recently emerged field of agroecology.

In one of the agroforestry systems crops are harvested between rows of trees or shrubs. Trees not only just prevent soil erosion but also generate more humus including other climatic benefits. They also provide shade and a cooler environment to shade loving plants and animals, thus increase agricultural productivity. Agroforestry is not only concerned about enhanced economic benefits to landholders, but also increase of sociocultural and environmental benefits to farming communities. [Ref. 7]

Figure7. Agroforestry practice in Haiti (Source: FAO, Ref. 7)

Check dam

All of the above soil conservation methods are applicable only if there is enough moisture in soil. Check dams are barriers constructed across seasonal streams. Barriers could be masonry work, loose

stones or barriers created by shrubs, grasses and trees (live check dam) across gullies. Check dams reduce velocity of runoff water flow, thus preventing soil erosion. A check dam also helps in recharge of ground water and allows cleaner water to flow downstream. [Ref. 8]

(A) (B)

Figure8. Check dam made from (A) masonry work and (B) loose stones (Source: Ref. 8).

Summary

Environmental Studies is the study of our environment. It is a multidisciplinary subject which needs contributions from physics, chemistry, and biology to understand the working of our environment. It requires help of mathematics and computer science for modeling environmental processes. It needs help from engineering to develop workable solutions to resolve environmental problems. The social sciences (economics, sociology, law etc.) is needed to understand the impact of the environment on human societies and what societies and governments can be motivated for implementing solutions to improve the environment. Environmental Studies dealt with global, local and individual problems. Experts in environmental studies, especially environmental engineers are now needed in every manufacturing plan and big laboratories. They are also working as environmental journalists and green marketing experts. Restoration of degraded ecosystems also needs expertise in environmental studies. A sound understanding of environmental studies is also to develop green technologies for various transportation, energy, consumer goods manufacturing, mining, civil construction etc. How our current economic model and technologies are hurting the quality of our environment and what is an ideal development model, is discussed first in this course. The problem of classical economics is, it treats the natural resources as one of the factors in production and to increase profit of businesses or GDP of a country as much as possible. Ecological economics considers the central role of the environment and human economy can only sustain if we utilize natural resources provided by the environment in a sustainable manner. Land is one of the important resources which support all terrestrial ecosystems providing vital services for our economy and survival. Unsustainable human activities are causing decline of this vital resource.

Key words

Environment, Multidisciplinary nature of environmental studies, Classical economics, Ecological economics, Sustainable development, Land resources, Green marketing, EHS experts, Environmental journalism, Conservation ecologists, Data science, Soil structure, Soil functions, Soil erosion, Desertification, Agroforestry, No-till farming, Check dam

Self assessment

. Environmental Studies is a……..

(a) Sub discipline of Chemistry

(b) Sub discipline of Biology

(c) Sub discipline of Geology

(d) Multidisciplinary subject

2. Ecology is essential to study our environment because it explains how……..

(a) Climate system work

(b) Landforms are generated

(c) We are connected to all living organism of Earth

(d) Current economic model are responsible for environmental degradation

3. Sociology is important in Environmental Studies as it explains…….

(a) Animal social behavior to environment

(b) How equity can provided us better environment

(c) How to maximize profits of businesses

(d) How to model climate system

4. Development of green energy technologies……..knowledge of environmental science.

(a) Always need

(b) Do not need

(c) Some time need

(d) None of the above

5. One of the professions based on environmental science is……

(a) Political journalism

(b) Cardiology

(c) Environmental journalism

(d) Telecom engineering

6. Ecological economics is concerned with how to enhance……

(a) Profit of businesses

(b) GDP of a country

(c) Human well-being

(d) All of the above

7. Sustainable development is meeting needs of present generation without compromising needs of……..

(a) Poor section of society

(b) Ancestors

(c) Affluent section of society

(d) Future generation

8. As per classical economics three factors of production are capital, labor and…….

(a) Mineral

(b) Land

(c) Bank reserve

(d) Oil

9. All natural resources needed for production of goods and services are part of……in classical economics.

(a) Capital

(b) Labor

(c) Land

(d) All of the above

10. Sustainable development is sustaining over interest of …….capital without depreciating it.

(a) Natural

(b) Produced

(c) Intangible

(d) Social

11. ……..capital comprises all ecosystems and mineral resources of a country.

(a) Produced

(b) Intangible

(c) Natural

(d) Social

12. Human capital is part of…….. capital of a nation.

(a) Natural

(b) Produced

(c) Intangible

(d) All of the above

13. Cost of crime is not included in the calculation of…….of a nation.

(a) GDP

(b) GPI

(c) GNP

(d) Both (a) and (c)

14. In desertification soil lost clay and silt by erosion leaving behind……

(a) Humus

(b) Water

(c) Sand

(d) Detritus

15. Overcultivation leads to soil erosion due to……which left soil vulnerable to wind and water erosion.

(a) Plowing of field

(b) No-till planting of seeds

(c) Irrigation of field

(d) All of the above

16…….is the most important component of land.

(a) Magma

(b) Confined aquifer

(c) Soil

(d) Mineral deposit

17. Integration of trees in farms is known as…….

(a) Strip cropping

(b) No-till farming

(c) Terracing

(d) Agroforestry

Answers

1.	D	2.	C	3.	B	4.	A	5.	C
6.	C	7.	D	8.	B	9.	C	10.	A
11.	C	12.	C	13.	D	14.	C	15.	A
16.	C	17.	D						

Review questions

1. Explain multidisciplinary nature of environmental studies.
2. Why should we study Environmental Science?
3. What is the scope of Environmental Studies?
4. How does the classical economic view of the economy hurt our environment? Explain.
5. What is ecological economics? How it promotes sustainable development.
6. What is a genuine progress indicator and how is it different from gross domestic product?
7. How Intragenerational and intergenerational equity is essential for sustainable development?
8. Explain the importance of land resources.
9. What are the causes of land degradation?
10. Discuss the methods of soil conservation

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Unit 02: Deforestation

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2.8 Forests and tribal population

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Answers for Self Assessment

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Objectives

After completion of this chapter you will be able to

- understand the benefits of forests.
- learn the importance of biodiversity in functioning of forest ecosystem.
- understand about the dependence of tribal population on forest.
- know the reasons behind decline of forest cover of our Earth .
- how can we retain the forest cover of our Earth, while fulfilling our economic goals.
- know new developments enhancing value of our forests.

Introduction

Forests are important natural resource as land, for our economy and survival. Forests are self-sustaining terrestrial natural ecosystem. The functioning of these ecosystems generates many important services to us. These services are categorized in three major categories: (1) provisioning services, (2) regulative services, (3) cultural services. In this unit we shall discuss what are these services, how are they important for us. We shall also discuss the causes of decline of our forest resources, even they are so vital for our survival. Some important practices and new developments to conserve our forest resources would also be discussed.

2.1 What are forests?

Forests are terrestrial (land based) ecosystems which are dominated by trees (Fig. 1). As per Food and Agriculture Organization (FAO) of US, forest is a land where trees are dominant life form and produce a canopy which covers more than 10% of land where the trees cover is less than 10% are termed as woodland. A forest is self-sustainable ecosystem made of plants (trees are dominant), animals, microbes and abiotic components supporting the specific biodiversity of the forest. The forests are mostly observed in region with comparatively high amount average annual of rain fall.

There are five major types of forests which exist on our Earth: tropical forests, deciduous forests, temperate forests, thorny forests and mangrove forests. We shall discuss in detail about these different types of forests in unit 4.

Figure 1: Forests: A Biotic Community Dominated by Trees.

2.2 Services provided by forests

The services provided by the forest could be in three major categories: provisioning services, regulative services and productive services. Let's discuss about them one by one.

Provisioning services

Different types of goods that we obtain from forests are termed as provisioning services provided by forests. Forests are the most productive terrestrial ecosystems. All the goods that are useful for humans are actually obtained from plants, animals and microbes which are constituent of a forest. These goods are either used for subsistence or sold in market to earn profit. The products obtained from forests are classified as major forest products and minor forest products.

Major forest products

Timber is major forest product. It include hardwood, softwood, wood chips etc. These woods are used by paper and pulp industries, construction industries, and chemical industries. The extraction of timber from forests in India is governed by forest department. Greater than 1.2 billion hectare of forests of world is managed for wood production.

Wood is natural composite made of cellulose fibers joined together by natural adhesive lignin. Paper and pulp industries extract the pulp from wood which is mass of cellulose fibers of wood. This pulp is used in manufacture of paper and products made of paper. The cellulose fibers of pulp are also used for manufacture of textile.

Wood logs are also converted to wafer-boards which are used in construction industries and in making of furniture (Fig. 2). There are many chemical industries which use wood as raw material for extracting chemicals which are component wood or derivative of constituent compounds of woods. These chemicals could also be obtained from the by-products of paper and pulp industries. Some of wood derived chemicals are charcoal, lignin, tall oil, pine oil, rosin, turpentine, tannins, methanol, ethanol, acetone, acetic acid etc. New processes are constantly being discovered to isolate commercially useful chemicals from wood or from by-products of paper and pulp industries, for example use of lignin in synthesis of phenol. [Ref. taking on all of the biomass..] Illegal logging is also one of the major causes of decline of forest cover.

Figure 2: Timber: an important raw material for industries.

Minor forest products

All non-wood forest products are called minor forest products. These are mentioned below.

Food: There are many food items which could be obtained from natural forests. The wild fruits, plant leaves, barks (kattha), fishes and wild animals (hunted by tribal and native village communities for centuries, but due to decline of population of many wild species this activity can led to extinction of species) are obtained by forest dwellers and villagers for subsistence. These wild food items are also sold by these people to earn their living.

Fodder: Forest also provides lot of other plants which could be used as fodder for cattle owed by villagers and tribal.

Fuel: Wood of many of the threes of forests could be used as fuel wood. The same fuel wood could also be converted to charcoal by local community.

Poles: Wood from bamboo and similar trees are used as poles for building homes in rural and forest areas.

Timber: The timber which is major forest product is also used by local communities making households items and for construction.

Fibers: Forests also provide fibers like jute and pliable thin wood which is used to make baskets, nets, ropes, strings etc. by local community.

Sericulture: Some supporting mulberry trees are also used for sericulture purpose by tribal and locals, which provides them precious silk fibers.

Apiculture: Forests are also used for apiculture for harvesting honey. Forest bees also provide useful pollination service.

Medicinal plants: Forests are also source of medicinal plants used traditionally by tribal and village communities to cure various ailments. These medicinal plants also are important raw materials for manufacture of many life saving drugs and discovery of new drugs.

Regulative services

There are many regulative services performed by forests whose overall value is much higher than value of all products obtained from a natural forest. These are discussed below.

Watershed protection

The big trees and other vegetation of a healthy forest generate ample amount of detritus and humus (the components of O-layer of soil) in forest soil. This absorbing layer of soil and roots of vegetation slows down the run off of surface water during rain fall and protects cities and towns situated at bank of river from flooding including flash flood. The root structure of forest vegetation and trees also stops the soil erosion. Further, the absorbed water moves down to unconfined aquifer and also

slowly moves along the slopes of the region and provide fresh water in water bodies throughout the year even during drought. Rich biodiversity in forest also helps in removing water pollutants from percolating surface run-off providing fresh and clean water (Fig. 3).

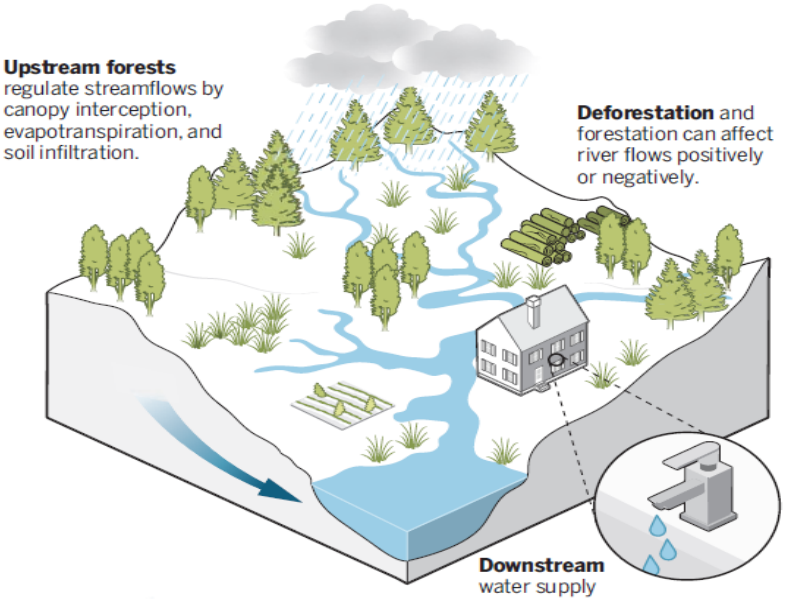

Figure 3: The connection of forests and water supply. (Source: Science, Ref.1)

Atmospheric regulation

Rich forest absorb a lot of solar heat through the process of evapo-transpiration and thus make the forested land and surrounding region cool during summer months. The evapo-transpiration and volatiles from healthy forest also help in rain droplet formation[2] and thus forested land receives more rain fall then other non forested land. In this way forest maintain the climate (average temperature and rainfall) of the region. Forest also absorbs a lot of carbon dioxide (CO_2) and releases oxygen (O_2) an essential gas for all animal life, in atmosphere.

Erosion control and generation of soil

Due to high amount of detritus addition and presence of rich biodiversity of soil organism, forest generate comparatively large amount of soil. In addition to that forest also conserves the soil by minimizing its degradation though air and water soil erosion.

Land bank

Form efficient functioning of biogeochemical cycles and higher primary productivity forest function as land bank which not only holds macro- and minor nutrients in soil, but also helps in maintaining optimum texture of soil trough help of soil organisms.

Cultural services

Our natural attraction to wilderness areas, which enrich us with peace of mind and spirituality are termed as cultural services provided by forests. This leads to generation of huge revenue through eco-tourism activities by a nation (Fig. 4). This attraction is contributed by aesthetic values associated with biodiversity. Forests are also revered as sacred by many communities of India. Beauty and magnificence of forests of ancient India is also mentioned in mythological literature of our country.

Figure 4: Eco-tourism is a cultural service provided by forests.

Did you Know?

Area wise Madhya Pradesh (MP) has the largest forest cover in India.

2.3 Overexploitation of forest resources

Once covering large area of our country, forest now covers only 23.5% of land area.[3] [Ref. One Darpan……] Forests supported many civilizations of our country for millennia. However, due to spread of agriculture and urbanization, forest cover of country shrank to patches. These patches of forests were largely controlled by tribal residing in these forests. The first of deforestation was realized during British Era of our country. A large amount of timber was extracted by British to construct their ships, furniture, building etc. which resulted in serious decline of output of timber from forests. This led to development of first scientific forestry program of our country. However, implementation of this program led creation of reserved and protected forests by British, which alienated tribal and local community from use and management of native forests. Ultimately British policy of alienation of tribal and local for being stack holder in forest management, resulted in further degradation and fragmentation of forest resources trough India.

Second era of overutilization of forest in our country started in early period after independence. People felt since the British had gone, so they could use forest resources as much as they want to raise their living status or earn maximum profit. Initial period after independence saw further decline in forest resources till 1970s. In 1970s we suffer serious problems due huge decline of services provided by forests especially regulative services such as flood control.

2.4 Deforestation

Reduction of forest cover is called deforestation (Fig. 5). Despite the huge importance of forests for our survival and wealth generation as discussed above, we are losing our forest cover. Let's first discuss causes of deforestation. The 2011 report of Food and Agriculture Organization of UN found out rate of deforestation was 7.3 million hectares per year. Most of the deforestation is happening in tropical countries (South America and Africa) which are developing nations and rich in forest resources.

Figure 5: Deforestation: Removal of three canopies of land.

Causes

Logging or timber extraction: Since timber is raw materials for paper and pulp, chemical industries manufacturing wood derived chemicals and also needed for furniture and building construction including domestic fuel and due to discovery of new uses of timber, it is some time harvested unsustainably. The unsustainable or illegal harvest of timber is one of the major causes of deforestation.

Expansion of cities: The rise of population is leading expansion of cities, more land are needed for construction of highway, housing complexes, commercial and industrial complexes to satisfy demands and generate the enough employments for rising population.

Establishment of industrial areas: To fulfill the demand of goods and services and gainful employment of rising population we need to establish more special industrial zone. This creates demand for more land and raw materials and results in clearing of forest land.

Mining: Most of the mining activities need removal of soil layers which results in destruction forest support by the soil.

Construction of dams: Dams submerge a lot of forested land in associated with catchment area of a river.

Shifting cultivation: Shifting cultivation is an ancient practice of agriculture, in fact agriculture started as shifting cultivation. Human started agriculture by clearing forested land using fire. The cleared land was used for two and three harvest and when soil fertility declined it was abandoned and new forested land was burned for agriculture. This practice is still prevalent in many tribal communities of India especially in hilly states of north-eastern India. Shifting cultivation leads to soil erosion and destabilize ecosystem of the region (Fig. 6).

Figure 6: Deforestation caused by shifting cultivation.

In all of above mentioned causes of decline of forest cover, mining and dam construction are one of the major causes of decline of forest cover in our country. Let's discuss about them in more detail.

2.5 Mining and deforestation

Mining is one of the major causes of deforestation, since many of rich mineral deposit are located in forested areas. These minerals are important raw materials for manufacturing of metal, alloys and ceramics needed for transportation, defense, industrial and domestic sectors. There is always conflict between environmental scientists advocating for conservation of forest resources and mining industries which support many other industries. Mining is one of the important activities to increase GDP and generate more employments in developing nations. But, minerals are non-renewable resource and forests are renewable if used sustainably, destroying forest for mining operation is like sacrificing long-term ecological gains for short-term economic gains. There is strict need of environmental impact assessment (EIA) for any mining project in rich forest areas.

Case Study: Mining in Aravallis

Aravalli hills spread from Gujarat, Rajasthan, Haryana and Delhi states of India. It supports thorny forest ecosystem and critical water recharge zone, climate regulator, wildlife habitat and barrier against desertification for national capital region. It supports 400 species of trees, shrubs and herbs; 200 native and migratory words; 100 species of butterfly; around 20 species of reptiles and around 20 species of mammals including leopards.

Aravallis hills are also the source of stones useful in construction industry and some minor minerals. The unscientific mining of stones in Aravallis in Haryana state (Gurugram, Faridabad and Mewat range of Aravallis) and no restoration and reclamation of used mines destroyed the unique thorny ecosystem of the Aravallis. This made Supreme Court of India to ban miming activities in Haryana state in 2009. [4] The State asked to open the mining in Aravallis again in Mar-2021 citing that State have to pay extra for sourcing minerals from neighboring states and opening of mining will generate more employment for State which is suffering from loss of employment due to COVID-19 pandemic. However, it should be emphasized that one of the cause of emergence of COVID-19 pandemic is destruction of habitat of bats, due to which bat was under stress that increases viral load in bat body and probably contributed to emergence of SARS-CoV-2.[5]

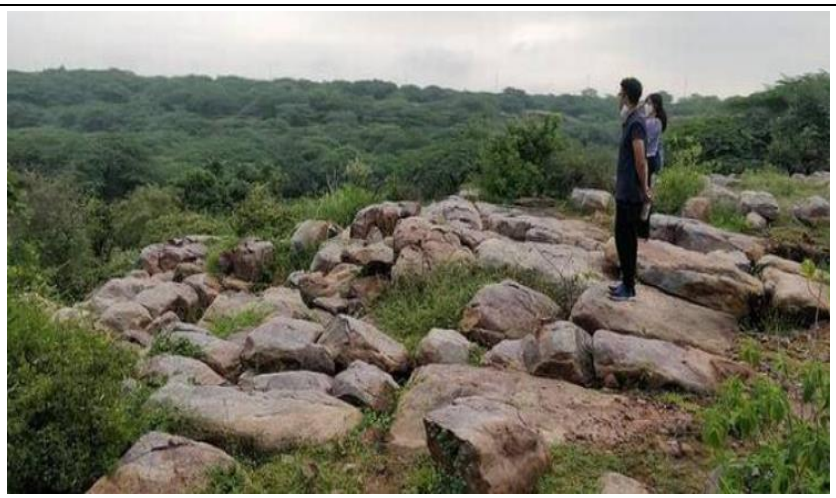

Figure 7: Thorny forests of Aravalli hills (Source: The Hindu).

2.6 Dams and deforestation

Dams are big high wall which raise the water level of a river to increase its potential energy. This increase in potential energy is converted to electricity by hydroelectric power plants. Dam also helps in storing fresh water and diverting it to areas suffering from water scarcity. Unfortunately, most ideal site for construction of dams are steep river valleys which are also covered with rich forest. These forests works as catchment area for providing water in river including controlling flood in river. The construction of dam leads to submergence of large forest area surrounding the river. This leads to the displacement of tribal living in these forests and decline of the services provided by the forests.

(A)

(B)

Figure 8: (A) Bhagirathi river with its steep forested embankments. (B) Submergence of forests by construction of Tehri dam over Bhagirathi river.

Case study: Sardar Sarover Dam

Sardar Sarover Dam is one of the major dams over westward flowing Narmada river. It was foundation stone was laid out on April 5, 1961 by then Prime Minister Pt. Jawaher Lal Nehru. A dispute originated between Gujarat, Madhya Pradesh and Maharashtra from where river flows which delayed the implementation of the project. The project was finally approved by planning commission on 1988. The dam is finally inaugurated on Sep, 2017. The construction of dam could provide drinking water to 4 crore people and can irrigate 22,000 hectares of land. However, this and other dams over Narmada river had submerged around 32 square kilometers of forest of Narmada river basin situated in central India. Many tribal peoples from places such Barvani district of Madhya Pradesh, have to leave their native villages due to submergence of their villages in river water. This massive displacement is the cause of Narmada Bacho Andolan (Save Narmada Movement) headed by Megha Patkar. Many of residents of these villages have not been properly rehabilitated as the villages were not recognized to get submerged due to rise in water level of the dam (Fig. 9).[6]

Figure 9: Submergence of village in Dhar district (MP) due to increase of water level in Sardar Sarover Dam. (Source: Down to Earth)

2.7 Impacts of deforestation

We have already discussed the importance of forests in terms services which we obtain from natural healthy forests. Impact of deforestation is simply the stoppage of provisioning, cultural and regulative services provided by them. Below are listed some these impacts of deforestation.

Loss of natural habitat of wild species: Destruction of forests means destruction of habitat of wild species like birds, leopard, butterflies, small shrubs etc. The loss of habitat can lead to loss abundance and richness of biodiversity. The biodiversity loss can affect the agricultural production and can cause emergence new epidemics.

Increase of intensity and frequency of extreme weather events: Loss of control of local climate by vast forest tracts can lead to more events of drought and floods. As all water during heavy rainfall just run away to river without being slows down and absorbed by rich forests leading to flood and no water in river during summer time due to no recharge of groundwater causing drought in the region.

Land degradation: With removal of forests the roots of big trees and other vegetation also destroyed and soil gets loosened and washed away. With removal of top soil fertility of soil is also lost.

Loss of forest products and revenue: With complete destruction of forests it is obvious that no major or minor forest product could be obtained and with government also losses its revenue.

Siltation of river and canals: The soil which is eroded due to removal of forest cover is finally accumulated in river and canals and increase the probability of flood during monsoon season in addition access silt in river also kill aquatic plant and animals of river.

2.8 Forests and tribal population

Forests can fulfill all basic needs of tribal living inside or at periphery of a forest. Forests provide them materials for construction of their homes (poles, timber, grasses etc.). Tribal people get their food through gathering plants, fishing, and hunting from forest. Forests also provide fibers for weaving baskets, nets, ropes and strings etc needed by tribal population. Forest dwellers also get fodder for their cattle, fuel wood for their daily cooking and medicinal plants needed for their

traditional medicine systems from forests. Most of the above products which are used by tribal for consumptive purposes are also sold by tribal to earn some income. We can understand why many tribal communities have tradition to worship the forests in the form of sacred groves (discussed in detail in Unit 14). The problem is tribal are not formally educated and many times have no link with mainstream society. This leads to their exploitation when their forests are destroyed for development projects. There is need to preserve tribal culture and livelihood by protecting their forests, in addition giving them access to modern education.

2.9 Sustainable forest management

There is always conflict between unsustainable exploitation of forests resources for goods or their removal to clear land for other uses and preserving them for their important services as discussed above. As per UN Conference of Environment and Development (UNCED) of 1992: "Forests are to be managed as ecosystems, with the objective of maintaining the biodiversity and integrity of ecosystem, but also to meet the social, economic cultural and spiritual needs of present and future generation." Lets first discuss need for sustainable development and then we would discuss how it can be achieved.

The need of sustainable forest management

One of the cause removal of forest cover is market value of wood and non-wood forest products is much less than profit generated from converting forests to pasture, and cropland or using them for industrial and housing complexes. As shown in the Figure 10 below, cost of all forests products (provisioning services of forests) is just Rs 30,000/- per tree, but cost of all regulative services provided by a forest comes out Rs 10,00,000/- per tree.

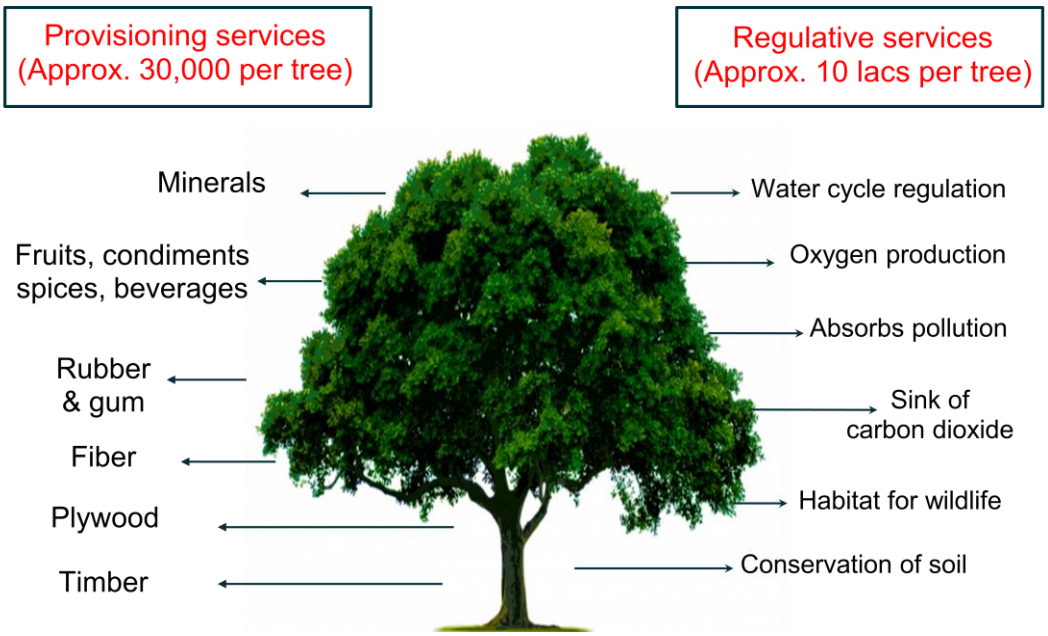

Figure 10: Comparison of provisioning and regulative services of a forest.

Sustainable Forestry

The measures need to achieve sustainable forest management are discussed below. Implementation of these scientific measures in forest management is called sustainable forestry.

Maximum sustainable yield (MSY): To satisfy the need of forest products of present generation in sustainable way while maintaining biodiversity and integrity of forests, one of aspects is calculation maximum sustainable yield (MSY) of harvested living resource of forest. It is the maximum possible rate of consumption of the resource so that rate of consumption should always be equal to rate of generation of resource. MSY concept is also applicable to discharge of pollutants in air and water and number of tourist allowed in a national park. We can use (or abuse by adding pollutants) natural system to a limit without any impact on quality and quantity of service obtained; if the limit is crossed then it leads to loss of regenerative capacity of natural system.

MSY can be calculated for harvested living resource (tree, herbs, wild animal etc.) from population growth curve of the living resource or species (Fig. 11).

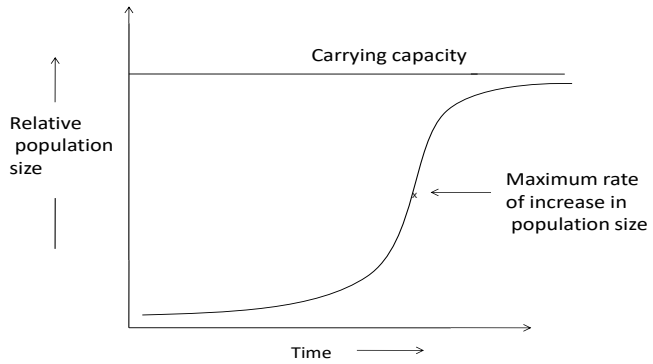

Figure 11: The logistic growth of population size.

As shown in Figure 11, if the population is relatively low then the harvest will also be low and it can make the species endangered. In this we should allow the population to grow, however if the population increased to very high number then it lead to competition among species for limited resources available in forest or other ecosystem and population increase is stopped to maximum level which is called carrying capacity of ecosystem for the species. In his situation sustainable yield could be increased by thinning the population to the point of inflexion in logistic growth curve of population. The rate of increase of population is highest at that point, so for sustainable yield rate of harvest should reach and equal to rate of population increase at inflexion point, which could be calculated from logistic growth curve of population increase.

There are limitations in calculation of MSY using above model. If the data on population and recruitment are inaccurate then it may lead to higher MSY. Second the carrying capacity of ecosystem varies year to year. It depends on weather conditions. Human impact on ecosystem (such as pollution and alteration of habitat) also affects carrying capacity including reproductive rate and recruitment (immigration) of new members of the species.

For wood harvesting in addition of MSY, the method of cutting of trees is also important. Clear cutting destabilize the forest ecosystem even afforestation is done to replace harvested trees. Shelter-wood cutting which allow the maintenance of canopy of trees is more suitable it does not destabilize the forest and there is no need of manual forestation as remaining trees can provide seeds and shelter for growing saplings. However, it needs more active management and skills.

Preservation of forests as national heritage or for eco-tourism: A forest could be protected as habitat for endemic and endangered species without exposing them for major or minor forest products. Still in many cases, it can generate more revenues than total revenue generated from the forest's products. Inclusion of indigenous villagers and tribal as partner in conservation of forests and sharing profit from eco-tourism is found to be more effective in preserving biodiversity and integrity of forests and raising living status tribal and native villagers.

India's National Forest Policy, 1988 given added importance to Joint Forest Management (JFM). A resolution in 1990 had given formal structure for community participation through formation of Village Forest Committee. Based on experiences of joint forest management, new JFM guidelines were formed in 2000. As per new guidelines, at least 25% income generated from given forest area should go to village community. JFM allowed formation of Forest Protection Committees comprising local community members. It participates in restoring the forest cover of area and protection of forests from being over exploited. Till 2002, there were 63,168 JFM managing 140,953 km^2 of forest area in 27 states of our country.

Did you Know?

Forest Stewardship Council (FSC) is a major international alliance of nongovernmental organization which certifies forest products for consumer market. Its motto is: "Forest For All Forever". More than 110 million hectares of forest land in 81 countries have been certified by FSC. Certification helps consumer to select wood products than have been obtained from sustainable managed forests.

Summary

Forests are biotic community dominated by trees. Forests are renewable natural resource vital for our survival and economy. The services provided by forests could be grouped in three major categories: Provisioning, Regulative and Cultural. Forests are cleared since the market value of major and minor forest products are not high enough. This leads to over exploitation of forests to maximize profit or removal of forests to use forest land for agriculture, housing or establishment of industries and infrastructure. By valuing a forest by just its provisioning services, we forget to the value of vital regulative and cultural services provided by forests. We can harvest forest products and utilize its other services continuously by sustainable forest management. Maximum sustainable yield model and inclusion of indigenous and tribal communities in forest management are two important aspects of sustainable forest management.

Key words

Forests, Provisioning services, Regulative services, Cultural Services, Watershed protection, Eco-tourism, Tribal, Mining, Dam, Joint Forest Management, Maximum Sustainable Yield (MSY), Timber extraction (logging), Flood, Sustainable forestry, Forest Stewardship Council (FSC), Major forest products, Minor forest products (non-wood products)

Self Assessment

1. Watershed of a river is an area which ……..

    (a) Is irrigated by the river
    (b) Is flooded by the river
    (c) Recharge river by rainfall received over it
    (d) Is not affected by river

2. The temperature inside and around the forest remained comparatively cooler due to……

    (a) Reduction of surface runoff
    (b) Absorption of solar heat
    (c) Evapotranspiration
    (d) Absorption of solar heat and subsequent evapotranspiration

3. …….. are called land banks.

    (a) Central Banks

    (b) Croplands

    (c) Confined aquifers

    (d) Forests

4. Which of the following is productive (provisioning) service provided by forests?

    (a) Recharge of ground water

    (b) Erosion control

    (c) Timber production

    (d) Habitat for biodiversity

5. Which of the following is regulative service provided by forests?

    (a) Provisioning of medicinal plants

    (b) Timber production

    (c) Provisioning of fibers

    (d) Flood mitigation

6. Which of the following is cultural service provided by forests?

    (a) Eco-tourism

    (b) Timber production

    (c) Local climate maintenance

    (d) Storage of carbon

7. Forest can fulfill the need of…….of tribal people living in forest.

(a) Food

(b) Shelter

(c) Fiber

(d) Food, shelter and fiber

8. Clean and fresh air is provided by forests due to the presence of diverse…….in forest.

(a) Animal

(b) Fungi

(c) Plant

(d) Microbes

9. Encroachment of forest land by local community happens due to……

(a) Rising population

(b) Fear of predators

(c) Lack of awareness regarding benefits of forest

(d) Both rising population and lack of awareness regarding of benefits of forest

10. Shifting cultivation is…….

(a) Cultivation of shifting communities

(b) Shifting of cultivation practice from one area to another by burning forests

(c) Cultivation of easily grown crop

(d) Shifting of crop land from one person to other person

11. The goods obtained from forests worth Rs 30,000/- per tree, while cost of regulative services can be up to Rs…….per tree.

(a) 3000/-

(b) 10,00,000/-

(c) 30,000/-

(d) 100,000/-

12. Clearing cutting of forest (removal of forest) can make many species endangered due to……

(a) Decline of oxygen in atmosphere

(b) Decline of rain fall

(c) Loss of habitat

(d) Loss of groundwater

13. Destruction of forest can cause land degradation due to erosion……soil.

(a) **Top soil**

(b) Bed rock

(c) River bank

(d) Confined aquifer

14. Sustainable forest management is exploitation of forest's services while maintaining …..……..

(a) It for fertile soil

(b) Biodiversity

(c) It for increased timber production

(d) Useful minor-forest products

15. One of the options of locking carbon dioxide is construction of……..

(a) More concrete buildings

(b) All wooden multistory buildings

(c) More highways

(d) More telecom towers

Answers for Self Assessment

1.	C	2.	D	3.	D	4.	C	5.	D
6.	A	7.	D	8.	C	9.	D	10.	B
11.	B	12.	C	13.	A	14.	B	15.	B

Review Questions

1. What are forests?
2. Classify various services provided by forests.
3. How forests and availability of fresh water are linked? Explain.
4. Explain impact of large dam on forests with example.
5. Explain impact of mining on forests with one example.
6. What are consequences of deforestation?
7. Why we need sustainable forest development?
8. How can we manage our forest resources sustainable?

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Unit 03: Water

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3.7 Non-renewable alternative energy sources

3.8 Renewable alternative energy sources

Summary

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Objectives

After completion of this chapter you will be able to

- understand about freshwater and why its availability is scarce.
- know the sources of freshwater.
- understand the importance of freshwater for our economy and survival.
- learn the impacts of overexploitation of groundwater.
- differentiate types of floods and droughts.
- know about conflicts caused by water scarcity.
- know how energy demand grows as rise of GDP of a nation.
- what are renewable and non-renewable energy resources.
- understand about the current energy crisis.
- significance of geothermal energy as alternate energy resource.
- significance and hurdles associated with nuclear energy as alternate energy resource.
- know how hot water springs originate and what are geothermal heat pumps.
- significance of solar energy as alternate energy resource.
- significance of wind, hydroelectric and tidal energy as alternate energy resources.
- what is biomass energy and how could it stop the addition of carbon in atmosphere.

Introduction

In this unit we would discuss about importance of water and energy resources. We would first learn about how our life and economy are dependent on availability of freshwater. The overexploitation of freshwater, due to rise of population and prosperities of nations has led to may

conflicts within and among nations. Similar to freshwater energy is also a vital resource for increasing GDP of a nation. The heavy dependency of our economy on use of fossil fuel is the main cause of climate change and rising air pollution in metro-cities. In this unit we would talk about current energy crisis and what are the solutions to resolve our energy crisis. We would discuss the significance and hurdle associated with alternative energy resources.

3.1 Freshwater use

Water is a fundamental requirement of all life forms including humans. Up to 60% of our body mass is made up of water. Most of our vital cellular processes (respiration, digestion, cell division etc.) are powered by enzymes, receptors, ions which are evolved to function in water. Fortunately, 75% of our Earth is flooded with water. However we are still suffering from a water crisis as approximately 97% water available on Earth is saltwater mostly confined in oceans. The remaining 2.5% freshwater which is available for human use 1.7% (of total water available on Earth) is trapped in polar ice caps. Only 0.8% freshwater is available for human use in form of surface and groundwater, of which approximately 0.003% is economically viable for human utilization. This explains our current problem of the freshwater crisis. Before discussing the current freshwater crisis let's first discuss how our economy and daily life is dependent on freshwater.

As we can see in figure 2, biggest consumer of freshwater in our country is agriculture sector. It is followed by domestic sector which consumed 6% out of 710 billion cubic meters (BCM) water withdrawn in India in 2010. Industries are third biggest consumer of freshwater in our country. Iron and steel industries consumed 22 cubic meters per ton of steel produced, while paper and pulp, textile and jute, and inorganic chemical industries consumed 200 cubic meters of freshwater per ton of production in the same year. Power plants (thermal and nuclear) are fourth biggest consumer of freshwater. The boiler used in power plants and other industries need soft water and freshwater cost less to be converted to soft water then saline water. Power plants also need a lot of water for cooling of spent steam using cooling towers. For sustainable use of precious freshwater resource, amount of water withdrawal should be almost equal to amount which is recharged by runoff (vide infra) of the region. However, freshwater demand of most of countries is increasing with the rise of population and GDP of these countries. For example, the freshwater withdrawal of India is projected to increase to 1180 BCM in 2050, while it was 710 BCM in 2010 (Ref. 1). Let's discuss in detail use of freshwater in our daily life and in production of food.

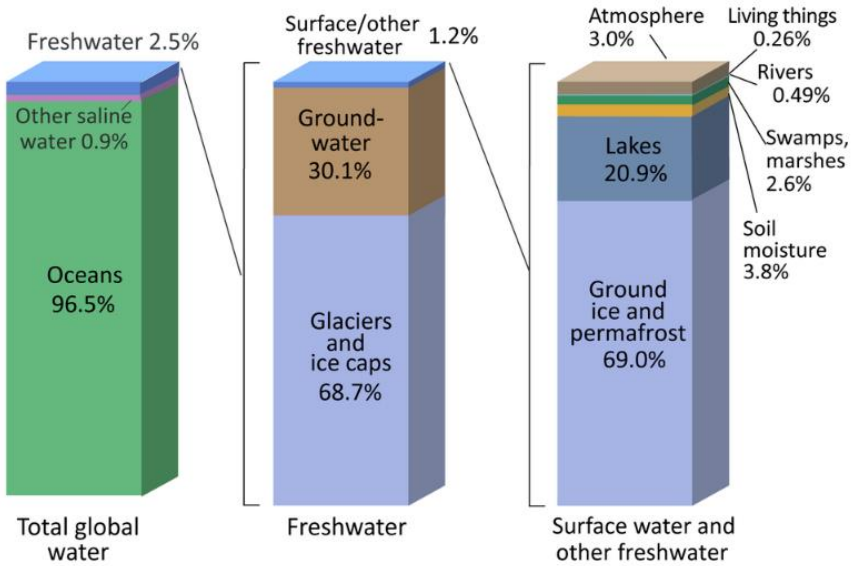


Figure 1. Distribution of water on Earth (Source: USGS)

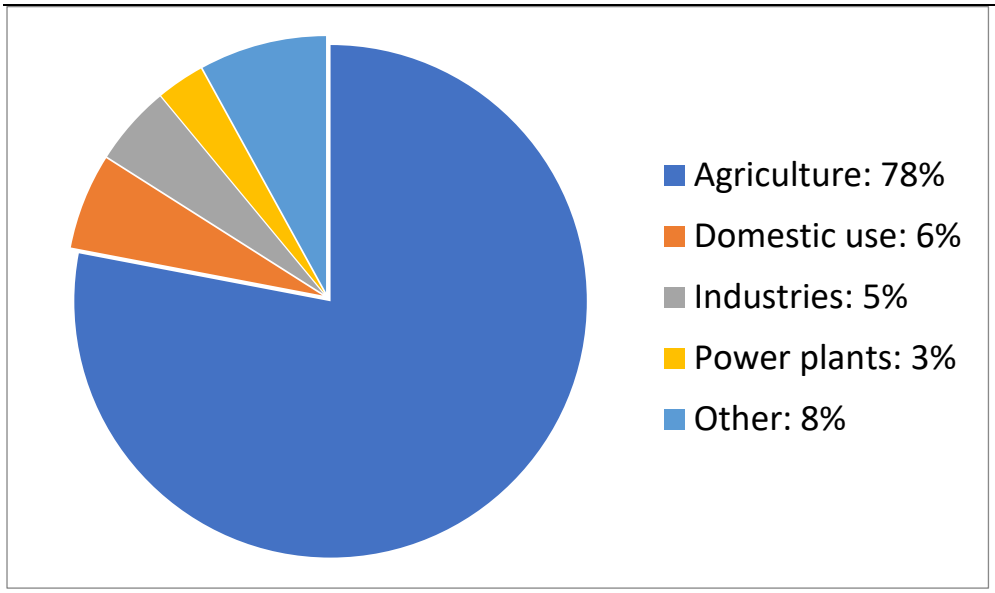


Figure 2. Sector wise freshwater use in India in 2010 (Source: Central Water Commission, Ref. 1)

3.2 Freshwater use in our daily activities and agriculture

There are two types of water usage: consumptive and non consumptive uses. In consumptive use, water used for one purpose is not available for any future use as it is mostly lost due to evaporation. In non consumptive use, water after its use is made available for other purposes also, for example water withdrawn for cooling towers by thermal power plants is discharged back into the water body which is suitable for other purposes such as irrigation. The water withdrawal is related to water usage as per the following equation:

Withdrawal = Consumption + Returns (1)

Return water based on its source is called sewage water (domestic), industrial effluent (industries), agricultural runoff etc. Another important term related to water usage is runoff of a region. The runoff is the difference of amount of water obtained from precipitation and amount of water lost by evapotranspiartion on land. This is the water which returns to the ocean as streamflow and groundwater flow. The annual runoff of a country could be higher than average rainfall as it also includes runoff received from watersheds which exists in other country.

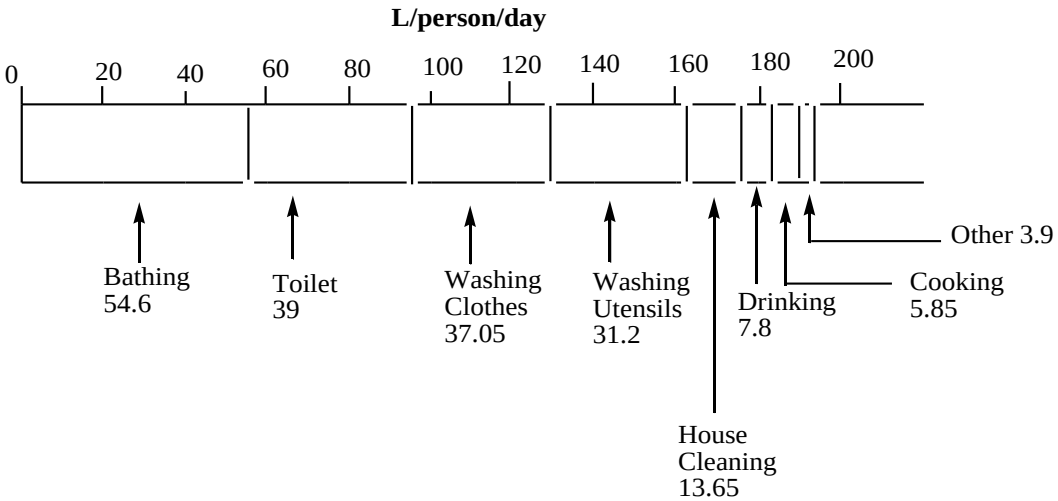


Figure 3. Water consumed (in L) by average urban Indian (Source: Frost & Sullivan)

Table 1 shows daily freshwater demand for our various essential activities, while figure 3 shows freshwater consumed by an average urban Indian. As shown in figure 3, one third of freshwater is used for toilet flushing, another one third is used for bathing and remaining is used for cooking, washing, drinking etc. Table 1 also shows how our food production is heavily dependent on

availability of freshwater, for example one pound of cotton production needs 7730 l of freshwater, if this amount is not available then it may lead to crop failure.

Table 1 Usage of freshwater (Source: [1]Ref. 2, [2]Ref. 3)

Water Usage	Amount (L)
Household water usage[1]	
Standard toilet, per flush	10-30
Ultralow volume toilet, per flush	6 or less
Shower head, per minute	20-30
Low flow shower head, per minute	6-11
Dishwasher, per load	50-120
Water saver dishwasher, per load	40-100
Agricultural Items[2]	
One egg	150
Glass of milk	380
One pound (≈ 0.45 Kg) of rice	2120
One pound of cotton	7730

3.3 Freshwater Resources

As the population and affluence of nations are increasing so the requirement of freshwater is also increasing (for example total withdrawal in the US in 1990 was 100 km^3, which got increased to 476 km^3 in 2000). This is leading to more withdrawal of surface and groundwater than runoff received by the region, a situation which is called over-exploitation of freshwater. Before discussing problems associated with over-exploitation of freshwater, let's understand the hydrologic cycle which is responsible to replenish our freshwater reserves (surface and groundwater).

Hydrological cycle

Though the majority of water (97%) available on Earth is saline water, desalination powered by the sun evaporates some 505 thousand cubic kilometers per year. Solar energy also removes a lot of water from leaves of plants through a process called transpiration. The combination of the two processes is termed *evapotranspiration*. The evapotranspiration consumes 4000 times more power than is needed by the human community of Earth.

As shown in figure 4, evapotranspiration removes approximately 577 (505 + 72) thousand cubic kilometer water per year. The moisture laden air masses over the ocean got condense in the form of clouds at higher latitude as air expanded and got cooled. The further cooling of clouds leads to precipitation. Of the 505 thousand cubic kilometers of water evaporated from oceans 458 thousand cubic kilometers returned back to the ocean every year in the form of precipitation. Remaining 47 thousand cubic kilometer moves to continents by moving air, it is added with evapotranspiration from land (72 thousand cubic kilometer per year) resulting in 119 thousand cubic kilometer rainfall over continents every year. However, of the 119 thousand cubic kilometer rainfall over land only 47 thousand cubic kilometer becomes available for us in form of runoff since rest amount of rainfall water gets converted to water vapor (Fig. 4).[Ref. 4]

Groundwater

As rainfall water comes to the ground it is either soaked by ground (infiltration) or runs off the surface. The ratio of infiltration to run off is called *infiltration-runoff ratio*. Water which runs off over

ground; finally enters the stream, river, lakes, ponds and other water bodies. These water bodies together are called surface water resources. The water flowing in the river and streams ultimately makes its way to the ocean from where the rain water comes to land, thus completing a loop in the hydrological cycle.

The water which infiltrates the ground has two fates. It may become the part of soil moisture held in capillaries found in soil texture. This water is called *capillary water*. Some water percolates further down in soil profiles due to gravity, reaching a level where soil is completely saturated with water. The level where soil is completely saturated with water is called the water table of the region and accumulated water below the water table is called groundwater. The groundwater is something which is available for human consumption, while soil moisture could only be used by plants through its roots by a process of transpiration. The groundwater could be used by humans through extraction from well and bore well. The infiltration of rainwater to soil capillaries and its further entry in the atmosphere through evapotranspiration forms a second loop in the hydrological cycle.

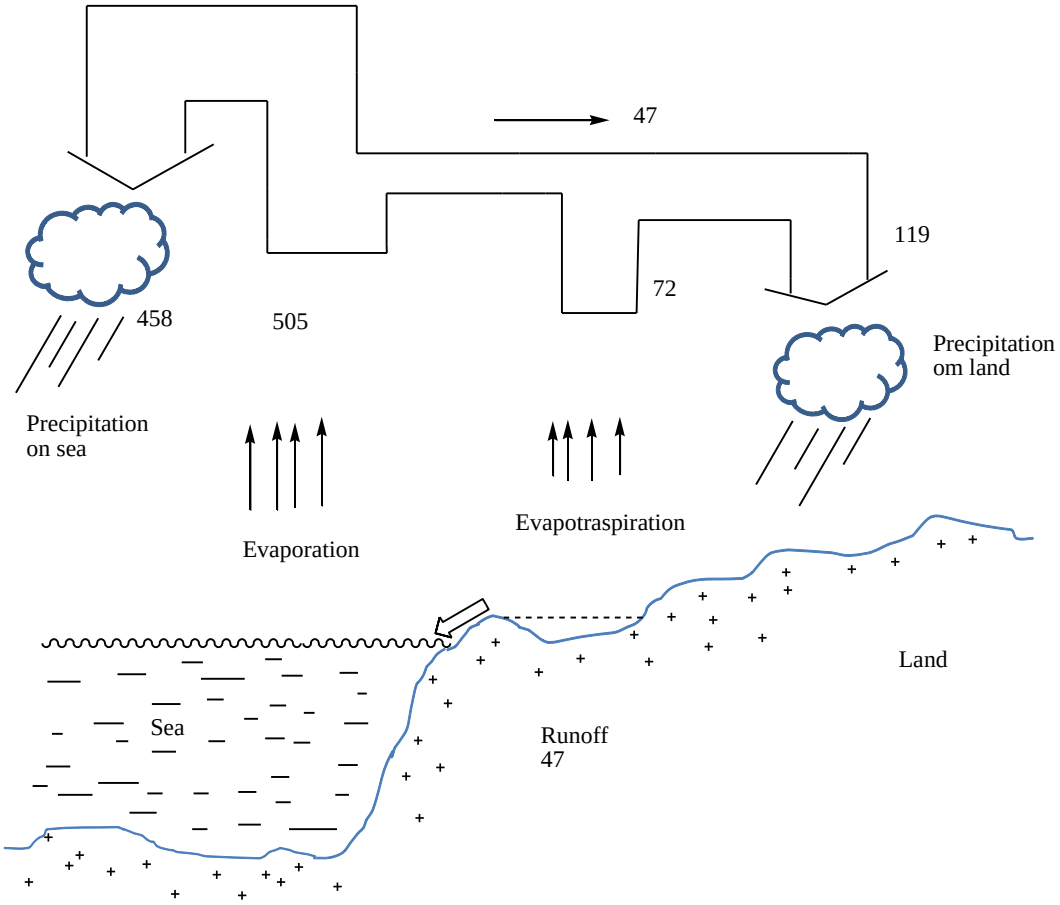


Figure 4. Hydrological cycle. Units are 10^3 km^3/yr

There are two types of groundwater sources which are called confined aquifers and unconfined aquifers. Groundwater reserves which are formed due to percolation of water to a level where soil is completely saturated with water are called unconfined aquifers. While freshwater reserves which are formed where water accumulates in hollow bedrocks or caverns is called a confined aquifer. Underground water moves along the slopes and when an aquifer intersects a ground surface in a valley or other depression then it comes to the surface as seeps or spring. The recharge area (where water enters in an aquifer) of a confined aquifer may be much far away from the place water leaves the aquifer (Fig. 5). The confined and unconfined aquifers of the world hold 99% of freshwater, while rest is found in lakes, rivers, ponds etc. The entry of water in aquifers and its emergence to the surface again forms the third loop in hydrological cycle.

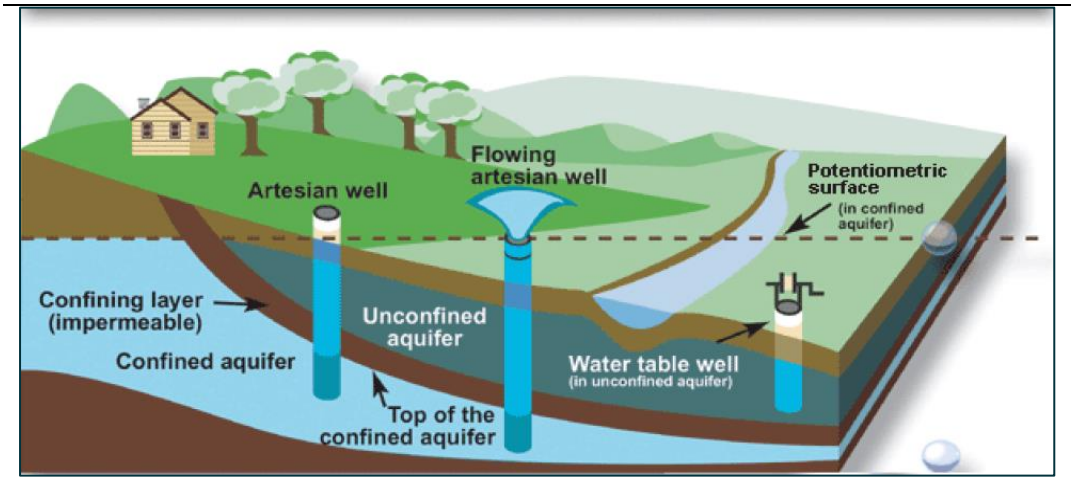


Figure 5. Confined and unconfined aquifers. (Source: USGS)

As shown in figure 5, wells which are used to extract groundwater are of two types: 1. water table well which source water from unconfined aquifer and 2. artesian well which reaches till a confined aquifer. The artesian well could also be of flowing type if the well height is below the potentiometric surface of the confined aquifer.

Over-exploitation of freshwater resources

The demand for freshwater in the past half century has tripled due to more than two times the rise of world population. This demand would further increase in the future also as 2 billion more people would be added to the world's population till 2050. The rise of population and affluence is leading to over-exploitation of freshwater resources, a situation where recharge rate of resource is lower than consumption of the resource. Let's discuss what the impacts are of over utilization of freshwater reserves.

Surface water over-exploitation

Many big cities are situated at the banks of big rivers or lakes. To satisfy the demand of freshwater mostly dams or barrages are constructed to divert the river water to remote areas through canal system. Use of dams is more prominent for storage and diversion of river water. All over the world there are 48,000 big dams (height more 50 feet) which trap 65% of ocean going water.

Dam Impacts

Dam not only submerged forests of watershed regions, but also affected downstream river ecosystems due decline of river flow. Damming of river affects movement fishes such salmon which move upriver from sea for hatching. This leads to decline of fish population and also affects terrestrial ecosystems since aquatic food chains are linked with terrestrial food chains and terrestrial wildlife is dependent on the amount of water in downstream rivers. Dams also interfere with deposition of nutrient rich fertile soil in downstream portions of the river and reduce recreation potential (hiking, river rafting etc.) due lack of water downstream. Dams destroy river ecology.

Diversion of river water also increases salinity in downstream portions of the river especially when water is diverted for irrigation projects. Diversion not only reduces the amount of fresh water downstream but also returns agricultural runoff and adds a lot of salt in the river.

Impacts on Estuaries

Diversion of river water has a serious impact on river estuaries. Estuaries are land areas where the river mixes with seawater. These are one of the most productive ecosystems on Earth. Biotic components of estuaries are fishes, waterfowl, shellfish etc. Diversion of river water provides less freshwater to estuaries. The decline of freshwater in estuaries increases concentration of salt and adversely affects its ecology as explained in the case study mentioned below.

Case Study: Impact of surface water diversion on San Francisco Bay

Figure 6. San Francisco Bay Estuaries. (Source: USGS)

San Francisco Bay is suffering from decline of freshwater input (more than 60%) as water is withdrawn at Central Valley (to irrigate 2.5 million acres of land) and at southern California to supply municipal water to 25 million residents. Without pressure created by flowing freshwater saline water from Pacific Ocean intrudes into the San Francisco Bay. The increase of salinity of the Bay Estuaries resulted in the disappearance of Chinook salmon, and great reduction of population of Sturgeon, Dungeness crab and striped bass population. Exotic species of plants and invertebrates are replacing native species in the Bay. The tidal wetlands of San Francisco Bay have been reduced to 8% of their former extent. [Ref. 5]

3.4 Groundwater over exploitation

Groundwater is a large invisible freshwater reserve (aquifers) below the ground which accumulated over millennia in porous rocks, soils and underground caverns. Some aquifers could be designated as fossil water as they may take centuries to recharge. Many aquifers in arid regions almost have no recharge. These aquifers are termed nonrenewable freshwater reserves. For renewable aquifers if the rate of withdrawal is greater than rate of recharge then it leads to decline of the water table. Decline of the water table has several adverse impacts which are discussed below.

Reduction of surface water flow

As shown in figure 5, groundwater tables intersect the surface in depression of river bed forming seeps and spring. Similarly, due to higher water table than elevation of wetland a lot of freshwater flows in wetland. Declining water table dries up flow from river bed springs and seeps which sometimes results in complete dryness of river and streams. Drop in water table also dry up wetland which adversely affects wetland ecosystems even leading to crowding related outbreaks of diseases like avian cholera and botulism due to reduction of availability of food and open water for migratory birds. (Ref. 6)

Ground subsidence

For millennia groundwater accumulated in cavities of bed rocks. The water in these cavities supports the overlying weight of soil layers and built infrastructure. The declining water table also reduces the support provided to overlying soil and built infrastructure due to removal of water from pores of bedrock. The reduction of support provided by bedrock results in either gradual sinking of ground or sudden collapse of land creating sinkholes. The rate of gradual land subsidence may be 10-15 cm per year. In some cases (such as San Joaquin Valley in California), land has settled as much as 9 m due to over exploitation of groundwater. The slow subsidence of land results in cracks in building foundation, sever lines, water lines and highways.

The sudden collapse of land happens when completely drained out underground water caverns. Sinkhole can be as wide as 300 feet and depth could reach to 150 feet. They can destroy buildings, highways etc. Regions having limestone bed rocks are more vulnerable to suffer from sinkholes due to presence of many underground caverns.

Saltwater intrusion

In coastal regions groundwater discharges to the ocean through spring submerged in oceans. The decline of the water table caused by over exploitation of ground water leads to reduction of pressure of out flowing water which allows intrusion of saltwater back into aquifers.

Inland increase of salinity of groundwater is mostly caused by use of groundwater intensive irrigation resulting in water logging. Excess over withdrawn water returns back in aquifers dissolving salts present in soil and increases salinity of groundwater.

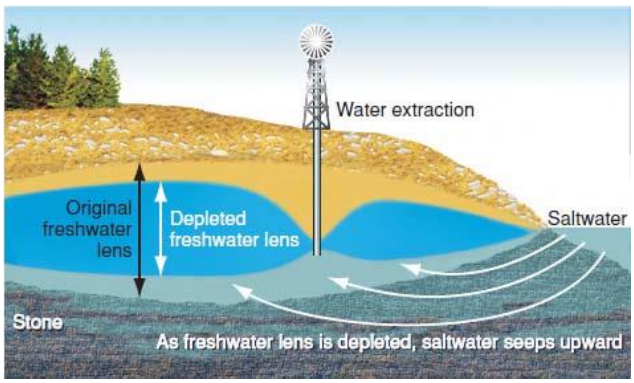


Figure 7. Salwater intrusion leads to coastal salinity. (Source: USGS)

Water calamities

Climate change is disturbing the distribution and frequency of rainfall in many parts of the world. The rise of average global temperature is interfering with coupled ocean atmosphere circulation models which are increasing water related adverse weather events such as drought and *floods*. The frequency of convergence of two cloud systems such as in case of extreme El Nino is increasing which mostly lead to flooding in the region.

Floods refer to the presence of unusually large amounts of water at any place or more water that can be handled by the drainage of the area. Construction of buildings on natural waterways, flood plains and inadequate drainage systems also increase the severity of flood.

Figure 8. Flood: the problem of excess water.

The floods incidents could be of three types. *Flash floods are* mostly caused due to clouds burst in hilly regions. Flash flood also caused by failure of dam and levees. Second type of flood is *river flood* which occurs due to gradual rise of water level in river due to continuous or heavy rainfall in catchment area of river. Third type of flood occurs in coastal regions and termed *coastal flood*. It is caused mostly due to tropical storms in India.

Droughts are conditions in which a region suffers from a severe scarcity in its water availability (Fig. 9). Droughts are also classified in three categories. *Meteorological droughts* occur when a region receives less than climatologically average for that region. *Hydrological droughts* are caused due to running down of surface water which leads to drying up of rivers, streams and lakes during summer season. Third type of drought is *agricultural drought*. These are caused when there is inadequate soil moisture resulting in acute crop stress and fall in agriculture productivity.

Figure 9. Cracked and parched landscape caused by drought. (Source: National Geographic)

Conflicts over water

The mismatch of geographical distribution of freshwater availability and human population leads to many conflicts within countries and between countries. Asia with 60% of the world's population receives only 36% of global runoff, while South America with 5% of the world's population receives 25% of global runoff. The rising world's population is further decreasing per capita water availability. On the basis of monthly water scarcity (defined as excess withdrawal of freshwater as is available sustainably) approximately 4 billion people of the world are suffering from water scarcity (Fig. 10). [Ref. 6]

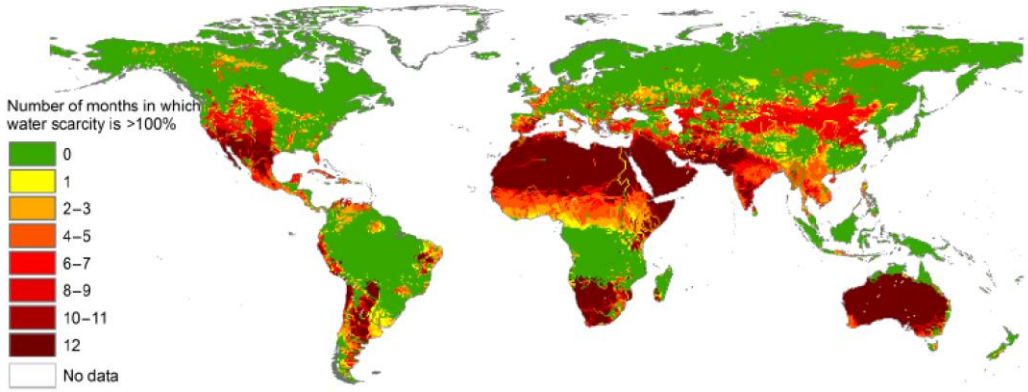


Figure 10. Global freshwater scarcity. (Source: Ref. 7)

Many nations depend on rivers for freshwater supply whose much of the watershed is located in other countries. Flow of the river is controlled by upstream neighbors. Below are listed few examples of international, national (inter-state) and local conflicts over distribution of freshwater supply.

Nile water conflict: Egypt and Ethiopia

Egypt depends on the Nile for 97% for its surface water supply while its neighbor Ethiopia controls almost all of the total flow of the Nile River.

Jordon River: Israel and Jordon

Israel and Jordon shares an uneasy dependence over Jordon River.

Brahmaputra River: India, China and Bangladesh

Brahmaputra River originates in Tibet region of China and supports much of the economy of Assam state of India. Proposal to construct dam over upstream part of river by China is cause of conflict with India. The dispute between India and Bangladesh is over management of Teesta River which is tributary of Brahmaputra River.

Cauvery River: Inter-state disputes between Karnataka and Tamil Nadu

Sharing of water of Cauvery River is the cause of a 100 year old dispute between Karnataka and Tamil Nadu states of India. The dispute intensifies during summer seasons when availability of water declines.

Local dispute: Industry versus community (Coca Cola Beverage Company in Kerala)

Local residents of Perumatty panchayat of Palakkad district of Kerala (which are mostly tribal farmers) opposed the operation of bottling plant of Hindustan Coca Cola Beverage Company since it resulted in decline of water table and pollution of groundwater.

According to 2018 report of Niti Aayog on the Composite Water Management Index (CWMI) , 21 major cities (Delhi, Bengaluru, Chennai, Hyderabad and others) may reach to zero groundwater levels by 2020.

3.5 Energy resources

Energy is also an important requirement similar to freshwater for our survival and functioning of various sectors of our economy. Energy is defined as capacity to do work. All animal species including humans get their energy from food. Humans also need additional energy for industries, transportation, agriculture, domestic and commercial.

Earth is a vast storehouse of energy, the wind and water flowing over it, the plants and other biomass, solar radiations, interior heat of Earth and fossil and nuclear reserves are all sources of energy, but still we are suffering from an energy crisis. To understand the current energy crisis, let's first discuss how our economy is dependent on energy.

Growing energy needs

As the GDP of a nation increases its total energy consumption also increases which is clear from figure 11 which shows a good correlation between per capita energy consumed by a nations (in units of Giga Joule or GJ) per capita gross national product in 1997.

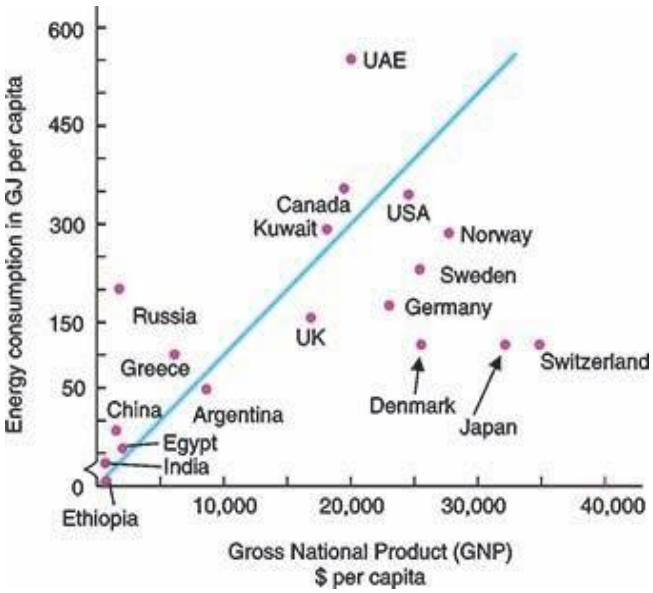


Figure 11. Per capita energy consumption versus per capita gross national product (GNP) of nations. (Source: World Resource Institute, 1997)

To understand the dependence of the economy on energy we can take the sector wise energy consumption in Indian economy.

As per International Energy Agency report total primary energy supply (TPES) of India in 2017 was 882 million ton oil equivalent (Mtoe). Of this demand only two third (554 Mtoe) primary energy was produced domestically, rest was imported. Total final consumption (TFC) of India has increased by 55% from 2007 to 2017.

As 2017 data, sector wise industry accounted for 56% of total fuel consumption (TFC). This is followed by the residential sector which consumed 29% TFC. Transportation sector is the third biggest energy consumer at 17% of TFC. Service sector which also includes agriculture comes in last with 12% of TFC in 2017 (Fig. 12).

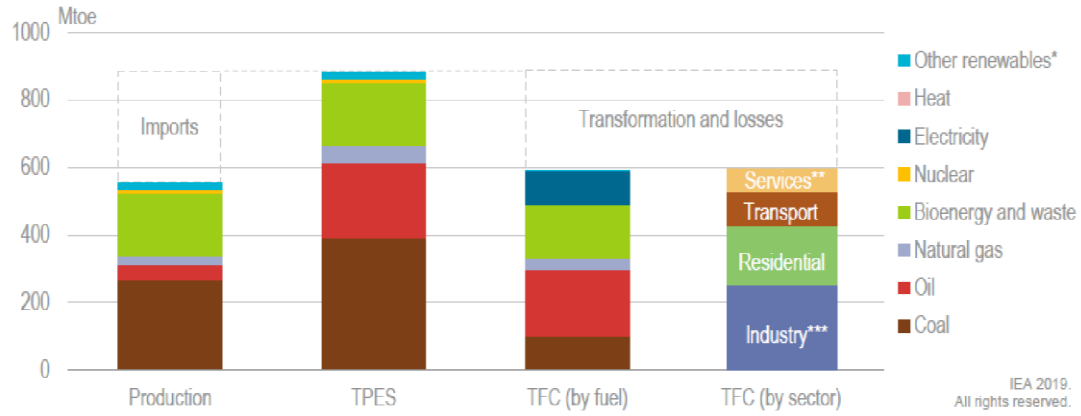


Figure 12. Sector wise and fuel wise energy consumption in India in 2017. Here, 1 Mtoe = 41.868 x 10^{15} J or 41.868 PJ. (Source: International Energy Agency)

Biomass accounts for the largest share of energy required by the residential sector which mostly need it for heating and cooking. Transportation sector is dominated by crude oil which fulfills its 95% energy need. Industry sector depends on use of all energy sources with fossil fuel accounting 56% of TFC.

Worldwide, the three kings of energy are: coal, oil and natural gas. This is also true for India as in 2017, around 80% TPES of the country was provided by fossil fuels. The Global contribution of fossil fuels in meeting the primary energy demand of the entire world was 87% in 2011.

3.6 The energy crisis

As mentioned in the above section, almost 87% of the world's primary energy need is fulfilled by fossil fuels (coal, crude oil, natural gas). Fossil fuels are non renewable sources of energy which are going to exhaust. Till how much time the fossil fuel reserves would survive; it depends on the rate of consumption. It is predicted that coal reserves would last for 200 years, natural gas till 70 years, and crude oil till 50 years. Though the exact year of exhaustion of fossil fuels is not known, it is a reality that they are going to finish. Given such a high dependence of human society on fossil fuel, it is highly important to find alternative energy sources to support national and global economies.

It is not just fossil fuels that are going to exhaust, but fossil fuels are trapped carbon dioxide. During Paleozoic and Mesozoic geological (100 to 500 million years ago) freshwater swamp and shallow seas supported vast amounts of vegetation and phytoplankton. The photosynthesis rate was higher than decomposition rate at that time. Low rate of decomposition led to accumulation of a lot of dead living matter at the bottom of sea floors and swamps. This organic matter is gradually buried under layers of sediments. The heat and pressure in the interior of Earth converted the buried organic matter to coal, crude oil and natural gas. Coal is less decomposed organic matter which could be found above depth of 7500 feet. However, heat and pressure increases below this depth and organic matter buried at depths of 7500 to 15,000 feet broken down further and converted to liquid organic molecules called crude oil. At a depth further below 15,000 feet organic matter broken down to the simplest one carbon containing molecule methane or natural gas.

Evolution of earth buried a lot of carbon dioxide in the atmosphere in the interior of the Earth crust. However, after the industrial revolution we started to release this carbon dioxide back into the atmosphere. Carbon dioxide is a greenhouse gas and rise of its concentration increasing radiative forcing towards Earth. The radiative forcing is increasing global temperature and changing Earth's climate. As per report of Intergovernmental Panel on Climate Change (IPCC) to stop irreversible change of our climate we have to achieve net zero emission of anthropogenic carbon dioxide in the atmosphere. (Ref. 8) The question is if we stop further use of fossil fuel then what are alternatives to fulfill our society's energy needs? Let's discuss alternative energy resources.

Alternative energy resources

Energy sources which do not add any carbon dioxide in the atmosphere are called alternative energy sources. In other words, forms of energy other than fossil fuels are termed alternative

energy sources. The alternative energy sources could be classified in two major categories: Nonrenewable and Renewable alternative energy sources.

Geothermal energy and nuclear energy are nonrenewable alternatives since geothermal sites could be cooled down in 150-200 years due to continuous heat mining and mineral reserves containing fertile and fissionable nuclear elements are limited on Earth. The energy extracted from geothermal sites takes hundreds of years to be regenerated so practically these are non renewable. Similarly, nuclear fuel once mined cannot be regenerated, so both these alternatives are nonrenewable.

Renewable energy sources are: solar, wind, tidal, biomass, hydro, ocean thermal and wave energies. All of these energy sources are non exhaustible and their total energy contained is many orders of magnitude higher than energy needed by the whole world still their contribution in global primary energy supply is very less. Let's understand what are the difficulties in increasing the contribution of above alternative energy sources.

3.7 Non-renewable alternative energy sources

First we will discuss the promise of geothermal and nuclear energies and problems associated in increasing their contribution to the world's energy supply.

Nuclear energy

The energy contained in the nucleus of atoms is called the nuclear energy. There are two ways to harness this energy: fission and fusion reactions of atomic nuclei. Presently, the most convenient way of harnessing nuclear energy is fission of heavy fissile nuclei. Currently, only three atomic nuclei are known to be fissionable: U-235, U-233 and Pu-239. Most of the nuclear reactors are thermal reactors which are based on the fission reaction of U-235. U-235 could be broken down in pair of smaller nuclei through bombardment of neutrons. As shown in the following reaction U-235 absorbs a neutron and is converted to unstable U-236, which is broken down to a pair of smaller nuclei such as Ba-141 and Kr-92 with liberation of additional neutrons.

$$_{92}U^{235} + {}_{0}n^{1} \rightarrow [{}_{92}U^{236}] \rightarrow {}_{56}Ba^{141} + {}_{36}Kr^{92} + 3\,{}_{0}n^{1} \quad (2)$$

If we calculate the difference of exact mass of fissionable nuclei and total exact mass of fission products then we can find a slight loss of mass during fission reaction. This lost mass is converted to energy as per Einstein relationship:

$$E = mc^2 \quad (3)$$

In above equation 3, m represents mass lost during fission reaction and c is velocity of light (3×10^5 km/sec). From this equation it is clear that a very small loss of mass can release a huge amount of energy. Further, generation of energy does not produce any carbon dioxide as happens during combustion of hydrocarbons of fossil fuels. However, this carbon free source of energy is associated with many problems. First is the majority of uranium available in nature (99.7%) in form U-238 which is non-fissionable, the fissionable U-235 is only 0.3%. To make the nuclear chain reaction critical we have to enrich the natural uranium with U-235, which technology is a difficult task. Only a few nations have access to enrichment technology and there is danger of leakage of this technology to terrorist and rogue nations, which may use it to generate weapon grade U-235 for making atomic bombs.

The other problem is disposal of generated nuclear waste. Equation 2 only shows one pair of nuclei generated during fission of uranium, but there many different combinations of nuclei generated during fission reaction and most of them are radioactive isotopes of various elements. It is not that disposal of radioactive waste is problematic as no one wants radioactive waste buried in their neighborhood. Further, the explosion of nuclear core or other accidents of nuclear power plants can release a huge amount of radioactive waste in the atmosphere. The construction of a nuclear power plant may need just US$1 billion, cleaning of a nuclear site after an explosion may cost more than US$10 billion.

The problem of very limited availability of U-235 was resolved by development of *Breeder Reactor* technology which can convert non-fissionable U-238 to Pu-239 as per the following reaction.

$$_{92}U^{238} + {}_{0}n^{1} \rightarrow [{}_{92}U^{239}] \rightarrow {}_{93}Np^{239} + \beta \quad (4)$$

$$_{93}Np^{239} \rightarrow {}_{94}Pu^{239} + \beta \quad (5)$$

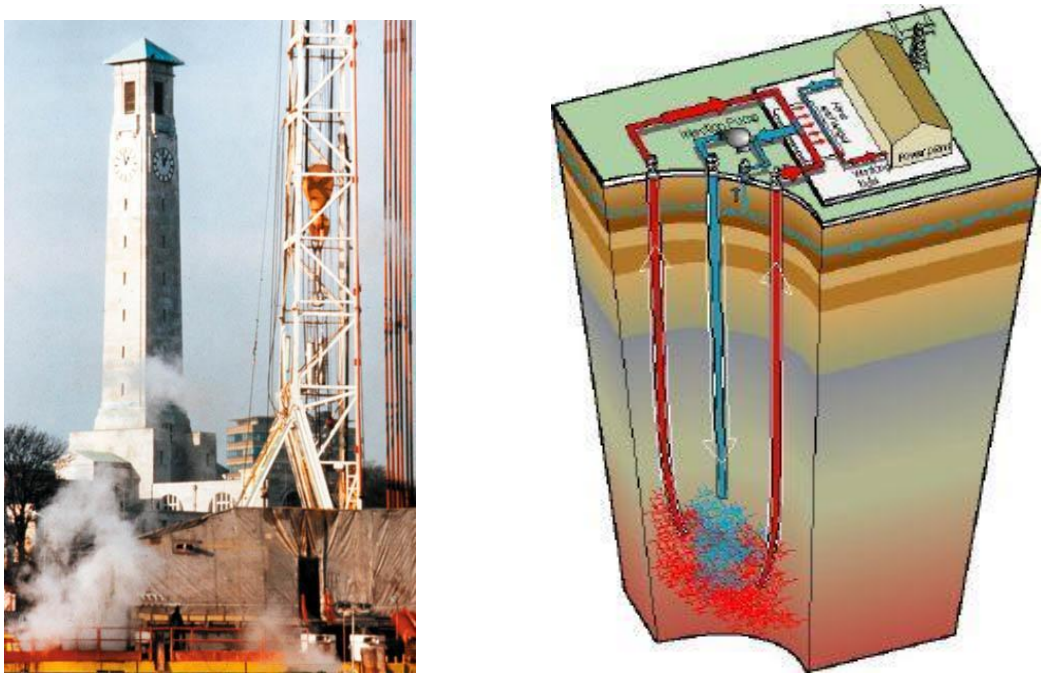
As shown in equation 4, bombardment of U-238 with a fast neutron converts it to unstable U-239 which is converted to another unstable isotope Np-239 through β-decay. Np-239 is finally converted to stable and fissionable Pu-239. The breeder reactor technology can satisfy the world's electricity needs for hundreds of years with available nuclear reserves. The problem is this

technology still needs improvements to be economically viable and there is danger of proliferation of nuclear arms as it is much easier to extract Pu-239 from stolen spent fuel rods than enrichment of U-235 since Pu-239 is a different element from uranium.

Geothermal energy

Geothermal energy is energy contained inside the interior of the Earth. Below the solid earth crust lies a mantle made of molten rocks. The convective currents in liquid mantle caused by decay of radioactive elements maintain an average temperature gradient of 30^{o}C/km as we move inside Earth. Hot water aquifers and hot rocks are two geothermal sites which could be utilized for harnessing geothermal energy in an economically viable manner.

Geothermal sites could be grouped in two categories: High temperature geothermal sites with temperature more than 150 ^{o}C and low temperature geothermal with temperature less than 150 ^{o}C. High temperature geothermal sites could be utilized for generation of electricity, while low temperature sites could be used to provide hot water to homes and industries. Let's understand the functioning of a geothermal power plant.



(a) (b)

Figure 13. Geothermal power plant.

As shown in figure 13(b), cold water is pumped in a geothermal site (hot aquifer or dry hot rock) though middle well. This water is heated above its boiling point, but due to high it remains in liquid form. The super heated water circulates through a primary loop in a heat exchanger and transfers its heat normal boiler feed water. Steam generated from boiler feed water runs the turbine. The super heated water directly coming from a geothermal site is not allowed to be converted to steam as it may contain some toxic heavy metal or radioactive elements or hydrogen sulfide.

Geothermal sites are mostly found near junctions of tectonic plates, so geothermal power plants cannot be constructed at any site. Further these are seismically active regions which makes them dangerous to operate. A simple way of utilization of geothermal energy is geothermal heat pumps.

Geothermal heat pumps are based on the concept that temperature below ground remains almost constant.

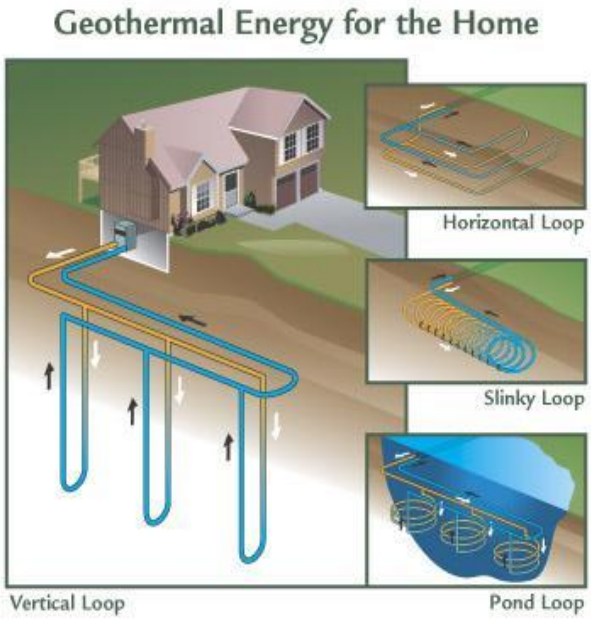


Figure 14. Functioning of a geothermal heat pump.

The constant temperature below earth surface could be utilized for space heating and air conditioning. We understand the functioning of a geothermal heat pump from schematic drawing of figure 14. If we try to heat air at supposed 6°C over the ground surface to air at 20 °C inside the building (see Fig. 14) then a high amount of electricity would be consumed by the building heating system. If we go below a depth of earth surface at around 100-150 m then we find temperature in the range of 12-14 °C . This underground surface could be utilized to preheat air inside home from 6 °C to 12 °C by passing it from underground loops (Fig. 14). Now heat of air of 12 °C to 20 °C will consume much less energy than is needed to heat air of 6 °C to 20 °C.

3.8 Renewable alternative energy sources

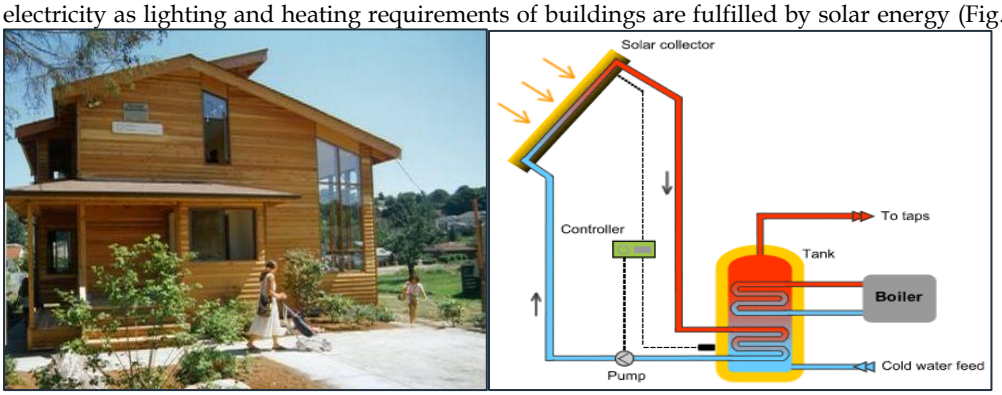
Let's discuss renewable energy options to resolve our energy crisis. In addition to being carbon free, renewable energy is also inexhaustible.

Solar energy

We can harness solar energy using two types of solar energy conversion systems: solar thermal and solar photovoltaic systems.

Solar thermal systems

Solar thermal systems are based on heating effects of sunlight. A very simple use of solar energy is in lighting and warming of buildings in cold countries. The use of solar energy to reduce energy consumption of buildings in lighting and warming is an important aspect of green building design. Simple use of large glass windows and right design can help us save a lot of fossil fuel derived electricity as lighting and heating requirements of buildings are fulfilled by solar energy (Fig. 15a).



(a) (b)

Figure 15. (a) Green building utilizing solar energy. (b) Solar water heater coupled with conventional energy.

Solar water heaters are another solar thermal device. The black and large surface area plates absorb a lot of solar heat which warms the water during the winter season. Further, coupling of this solar heater with conventional heating source can solve the problem of discontinuous availability of solar energy (Fig. 15b).

Solar thermal systems are also being used for electricity production. As shown in figure 16, use of parabolic concentrators focus the sunlight to pipes carrying high boiling oil. Oil could be heated up to a temperature of 700 ^{o}C. The heated oil is used to raise steam in the boiler. The steam is further heated to increase the efficiency of power plants using fossil fuel, however the consumption of fossil fuel is much less in these solar thermal energy based power plants.

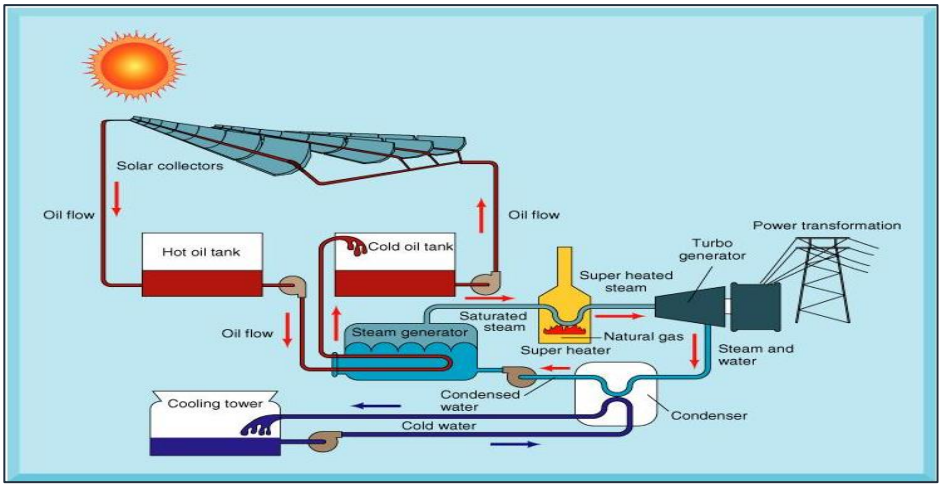


Figure 16. Solar thermal power plant.

Solar photovoltaic systems

Solar photovoltaic systems are not based on the heating effect of sunlight which is mostly caused by infrared radiation present in sunlight. Solar photovoltaic systems use visible portion of sunlight; they convert photons of visible light in electron hole pairs which are separated to cathode and anode of cell. Electrical connection of many solar cells in series creates a solar panel which could be used as roof top solar photovoltaic panels.

Efforts are going on to low cost polymer based solar cells, which could print on transparent flexible support. These lightweight organic solar cell based solar panel could be assembled in the form of solar tree which can save a lot of land area needed for constructing solar power plant (Fig. 17).

Figure 17. Photovoltaic panel based solar tree. (Source: Hindustan Times)

Hydropower

Hydropower is a carbon free conventional source of energy. It is based on capturing the kinetic energy of flowing rivers by making a dam across the river. However, submergence of land due to rise of river water level destroys forest of watershed and displaces people living near the bank of river. It also affects river and estuaries ecosystems. Because of these concerns the option hydropower as a carbon free energy resource is very limited.

Tidal energy

We can harness kinetic energy of flowing water during high and low tide in river estuaries. River mouth or river estuaries are the best site to harness tidal energy as river mouth high tidal range (difference of height of low and high tide). Simple construction of a retaining wall (tidal barrage) across the river mouth can help us to trap kinetic energy of tides. However, this tidal barrage can be very destructive of the biodiversity rich ecosystem of estuaries. Another option is use of submerged tidal turbines. These turbines have comparatively less impact on river estuaries. These can be installed in sea beds between islands where the speed of tidal currents remains high.

Wind energy

Harnessing kinetic energy of flowing wind is another option to obtain carbon free energy. Use of solar and wind energy are two most promising to increase contribution of alternative energy in total energy needed by our country. There is a plan to increase our renewable installed power capacity from current (2018) 70 GW to 175 GW by year 2022 to achieve nationally determined contribution for Paris agreement. This target would be met by increasing installed solar power to 100 GW and wind power to 60 GW. (Ref. 9)

The wind energy is harnessed using wind turbines. The power of flowing wind captured by wind turbine depends on the radius of turbine blades and speed of wind as explained below:

Energy density of wind $E = (1/2)\ \rho.u^2$ (6)

Here, ρ is density of wind and u is velocity of wind.

Wind passing through area A spanned by a turbine of radius r ($A = \pi r^2$) per second is A.u.

Hence the maximum power of wind captured by wind turbine is given by:

$P = E.uA = (1/2)A.\rho.u^3$ (7)

Advancement of material science and aerospace engineering has allowed constructing wind turbines with large radius and hub height. The current wind turbine has a rating of more than 5 MW. The offshore installation of wind turbines provides uninterrupted flow of wind (Fig. 18). Further, current wind turbines can change the direction and pitch of blades to harness maximum wind energy.

Figure 18. Modern offshore wind turbine.

Biomass energy

Biomass energy is energy contained in all matter produced by living creatures. Biomass energy contributes 68% of the energy need of the residential sector of India. Many times this source of energy is utilized in inefficient manner which also leads to an increase of air pollution. The most efficient ways of utilizing biomass as a source of energy are: anaerobic digestion, biomass gasification.

Anaerobic digestion, performed in biogas plants (Fig. 19) are most suitable for wet biomass such animal waste, aquatic weeds etc. The wet biomass is digested under optimized anaerobic conditions to methane (biogas is almost 65% methane) which is clean fuel with net carbon dioxide emission approximating to zero value. After digestion of biomass the residue could be utilized as useful manure.

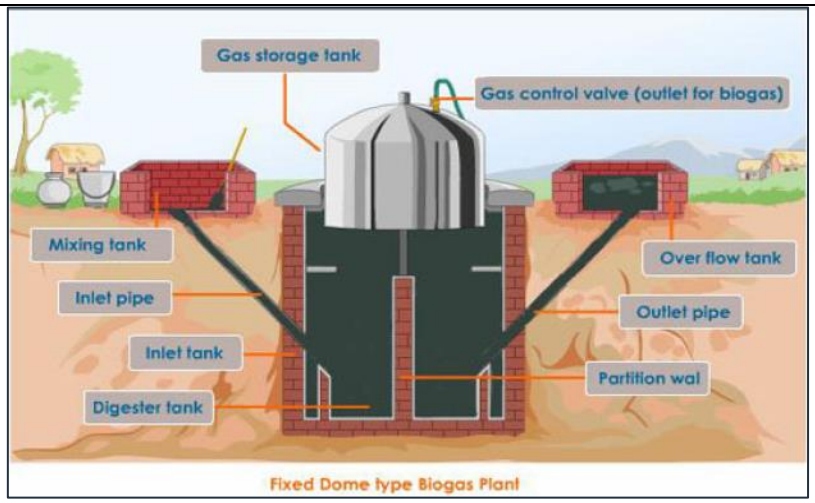


Figure 19. Biogas plant: Use of wet biomass.

Dry biomass is better utilized by converting it to clean gaseous fuel. In biomass gasification dry compacted biomass is burned under reduced supply of air.

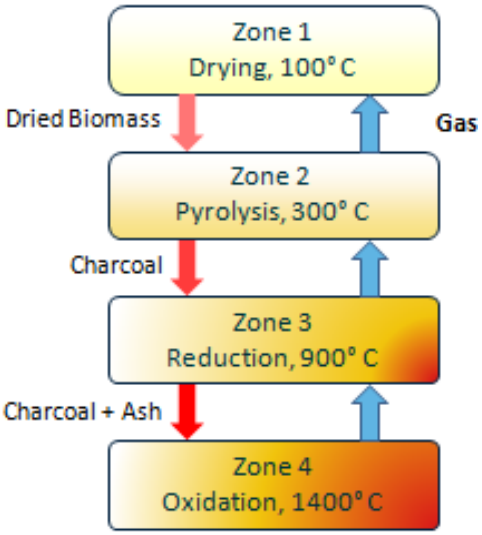


Figure 20. The process which goes on biomass gasifier.

As shown in figure 20, four zones get established in a biomass gasifier based on temperature differences. Different thermo chemical reactions go on in different zones. The gaseous products coming out from the outlet of the gasifier are CO, H_2, CH_4, CO_2, N_2. The gaseous mixture is also called producer gas could be utilized for process heat and running gas based generators for rural electrification.

Oil seed and corn is also used for generation of biodiesel (alkyl ester of long chain fatty acids) and ethanol. The energy output to input ratio is less than one for production ethanol from corn, but it is much better for conversion of oil from non edible oil seeds to biodiesel by transesterification using methanol.

Summary

Freshwater is an important resource for our survival and economy. Though 75% of our Earth is covered with water, only 0.8% (approx.) is available as freshwater for human use. Ninety nine percent of freshwater is contained in aquifers (groundwater) and rest is available as surface water. Agriculture sector of our economy is the biggest consumer of freshwater. We also need freshwater for drinking, cooking, washing, bathing etc. The rising population and affluence is leading to over-exploitation of the freshwater crisis in many parts of worlds. Over-exploitation of surface water via dams and diversion canal is killing river and estuaries ecosystems. Groundwater overexploitation is drying up rivers, streams and wetland especially in summer month. Groundwater overexploitation is also increasing the subsidence rate of ground and increasing salinity of

groundwater. Climate change is also increasing water related calamities such drought and flood. Declining availability of freshwater and its unequal distribution is leading to many international, national and local conflicts especially during water scarce months. Similar to freshwater energy is also an important resource for our economy. Energy demands increase with increase of affluence in a nation. India's energy requirement in 2017 was 882 Mtoe, which is consumed by industrial, residential, transportation and service sectors. Industries are the biggest consumer of energy followed by residential, transportation and service sectors in India. However, 87% of world energy need is fulfilled by fossil fuel. The three kings of energy are: coal, oil, and natural gas. Transportation sector of our country is almost completely dependent on the use of crude oil. The heavy reliance on fossil fuels is leading to an energy crisis, since fossil fuels are going to exhaust and increase carbon dioxide in our atmosphere which is responsible for climate change. To stop irreversible change in our climate we have to achieve net zero addition of carbon dioxide in the atmosphere. This implies we have to move our energy supply from fossil fuel to carbon free or alternative energy sources. The alternative energy sources are divided in two major categories: nonrenewable alternatives and renewable alternatives. Nonrenewable alternatives are: nuclear energy and geothermal energy. Renewable alternatives are: solar, wind, tidal, hydro and biomass energies.

Key words

Freshwater, unconfined aquifers, confined aquifers, hydrological cycle, dams, diversion of surface water, groundwater over-exploitation, ground subsidence, water table decline, groundwater salinity, loops in hydrological cycles, conflict over water, drought, flood, total consumption by fuel (TFC), total primary energy supply (TPES), geothermal power plant, geothermal heat pumps, hot water aquifers, thermal reactors, breeder reactors, solar thermal systems, solar photovoltaic systems, tidal barrage, wind turbine, biomass gasifier, biogas plant, tidal turbine

Self Assessment

1. Which type of water is most abundant on our Earth?

A. Fresh water
B. Saline water
C. Brackish water
D. Distill water

2. Availability fresh water on our Earth is_____

A. 97%
B. 3%
C. 100%
D. 50%

3. Which of the following sectors is the biggest consumer of freshwater?

A. Municipal (domestic)
B. Industries
C. Agriculture
D. Power plants

4. The water cycle recharges_____

A. Unconfined aquifers
B. Confined aquifers
C. Oil well
D. Both unconfined and confined aquifers

5. _____is a level in soil profile where soil is completely saturated with water.

A. Bedrock
B. Water table
C. Mineral table

D. Water line

6. The cause of inland water salinity is _____

A. Excessive irrigation
B. Sea water intrusion
C. High temperature
D. High Pressure

7. Which of the following is the cause of flash flood?

A. Violent wind
B. Cloud burst
C. Over exploitation of groundwater
D. Landslide

8. The biggest source of energy of the world is_____

A. Nuclear energy
B. Hydropower
C. Solar energy
D. Fossil fuels

9. The major source of energy of transportation sector is_____

A. Coal
B. Crude oil
C. Natural gas
D. Electricity

10. Alternative energy sources are energy sources other than _____

A. Fission energy
B. Hydrogen energy
C. Fusion energy
D. Fossil fuels

11. Which of the following energy sources is renewable?

A. Coal
B. Natural gas
C. Crude oil
D. Hydropower

12. Which of the following is a non-renewable alternative energy source?

A. Crude oil
B. Coal
C. Solar energy
D. Geothermal energy

13. Geothermal energy is energy contained inside_____

A. Biomass
B. Atomic nuclei
C. Earth
D. Crude oil

14. One of the disadvantages of nuclear energy is_____

A. Addition of CO_2 in atmosphere
B. Air pollution
C. Disposal ash
D. Disposal of spent fuel

15. Problem associated with breeder reactors is_____

A. Easy isolation of Pu-239 from stolen fuel rod for assembly of nuclear bomb
B. Poor availability of U-235
C. Poor availability of Pu-239
D. Large amount of CO_2 generation

16. Which of the following sites could be utilized for geothermal energy production?

A. River valleys with steep embankments
B. Off-shore sites with good wind speed
C. Hot water springs
D. Oil fields

17. Solar thermal systems are based on utilization of_____ of solar energy.

A. Cooling effect
B. Visible light
C. Heating effect
D. Magnetic effect

18. Solar photovoltaic systems covert _____ of sunlight to electrical energy.

A. Heat energy
B. Visible light photon energy
C. Chemical energy
D. Kinetic energy

19. Which of the following is a solar thermal system?

A. Solar geyser
B. Solar cell
C. Telescope
D. Biogas plant

20. Most suitable site for construction of tidal barrage is_____

A. Sea cost
B. Off-shore high wind site
C. Mouth of river estuary
D. Hot water spring

21. Energy harvested by wind turbines increases with_____ of turbine blades.

A. Increase of length
B. Decrease of length
C. Increase of weight
D. Increase of density

22. Energy of biomass could be utilized by use of_____

A. Tidal barrage
B. Wind turbine
C. Biomass gasifies

D. Aerobic bacteria

Answer for Self Assessment

1.	B	2.	B	3.	C	4.	D	5.	B
6.	A	7.	B	8.	D	9.	B	10.	D
11.	D	12.	D	13.	C	14.	D	15.	A
16.	C	17.	C	18.	B	19.	A	20.	C
21.	A	22.	C						

Review questions

1. The three fourths of Earth is covered with water, then why is there water scarcity? Explain
2. Explain our dependence on freshwater.
3. What are the impacts of diversion of river water for human use?
4. What are the impacts of over-exploitation of groundwater?
5. Explain various loops of the hydrological cycle.
6. Discuss types of flood and drought.
7. What is our current energy crisis?
8. Discuss the consumption of energy by sectors of the economy of India.
9. What are geothermal power plants? How do they work?
10. What are advantages and limitations of nuclear energy?
11. What is the difference between solar thermal and solar photovoltaic systems?
12. Explain the functioning of modern wind turbines.
13. How could we harness tidal energy?
14. Explain two most efficient ways of harnessing biomass energy.

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Unit 04: Ecosystem

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Objectives

After completion of this chapter you will be able to

- know what an ecosystem is.
- know what components of the ecosystem are.
- how the ecosystem works.
- know how energy flows in an ecosystem.
- laws followed during flow of energy through the food chain.
- know the importance of food web.
- know pyramidal patterns that we observe in an ecosystem.
- what is ecological succession?
- importance of ecological succession.
- know the major forests of our country.
- know the structure and function of Western Ghats forest.
- understand the structure and function of the Terai grassland of our country.
- know what desert and aquatic ecosystems are.
- understand the structure and function of the Thar Desert as an example of a desert ecosystem.
- know the structure and function of Chilika Lake as an example of an aquatic ecosystem.

Introduction

We have learnt that our life and well being are dependent on various natural resources. The natural resources are services provided to us by the ecosystems which exist on Earth. Ecosystems are distinct functioning units of Nature made from interaction of local climate, soil, water and other abiotic factors with specific living creatures (which are supported by the abiotic factors) found in a given geographical area. In this chapter we would learn about the structure of the ecosystem, and how the ecosystem functions as a distinct unit through interaction of biotic and abiotic factors. We would also study how a degraded ecosystem restores itself through the process of ecological succession. Finally as examples of ecosystems, we would learn how our Western Ghat forest, Terali grassland, Thar Desert and Chilika lake ecosystems function in a self sustainable manner.

4.1 Ecology: The science of organisms and their environment

Ecology is a biology subject. Biology is made of two major types of subjects. One category is made of Biology subjects; which tries to identify mechanisms of life processes at various levels such as molecular biology, cell biology, cardiology, neurology etc. Another category is made of subjects; which tries to explain why a particular species exists on Earth and what its significance to us such as ecology and its various branches. Ecology is a subject which is concerned with interaction of communities of species among themselves and with their physical environment.

There are five major branches of ecology:

1. Physiological ecology

2. Population ecology

3. Community ecology

4. Ecosystem ecology

5. Restoration ecology

Physiological ecology studies how a species is adapted to its physical environment to obtain water, nutrients and energy and sustain its essential life processes. For example, how a fish is adapted to swim and breathe inside water or how a bird can easily fly which are not possible for other terrestrial mammals. Physiological ecologists analyze a species for its morphological, behavioral, and metabolic or biochemical adaptation which makes it fit to survive in a given niche.

Population ecology is concerned with the issue of geographical distribution of population of a species. It also tries to understand factors which affect the increase or decline of population of a species in a given location or time. Population ecology provides a lot of help in conservation and revival of endangered species in a given ecosystem.

An ecological community is populations of different species which co-occur simultaneously in a given region. *Community ecology* is concerned with factors which affect the structure of ecological communities in an ecosystem; it also studies interactions which bind a community together.

Ecosystem ecology tries to understand how a community of species in association with all non-living (abiotic) factors found in a given geographical region forms a self-sustaining system called ecosystem. It also studies how the natural or human induced changes affect an ecosystem.

Since the ecosystem on Earth provides all resources (except minerals) which are essential for human economy and well being. We are trying to learn how to restore the degraded ecosystems. *Restoration ecology* is scientific study of man-made intervention which can work in the opposite direction i.e. towards restoration of degraded ecosystems. Whether it is conversion of desert back to grassland (or thorny forest) or conversion of salt water mangroves back to freshwater mangroves all are parts of restoration ecology. (Ref.[1])

4.2 Ecosystem: Sustaining life on Earth

Ecosystem is a functional unit of nature, made from dynamic interaction between its biotic and abiotic components. Ecosystems vary in size from small ponds to big forests. Ecosystems are

[1] Nature Education **2014** https://www.nature.com/scitable/knowledge/ecology-102/#:~:text=The%20Knowledge%20Project%20is%20an,independent%20of%20Nature%20Education%20Editors.

essential for sustaining life on Earth. Population of a single species cannot survive on its own; it needs ecosystems made from communities of species which are supported by the specific composition of abiotic factors of the ecosystem.

Ecosystems are characterized by their structure and its life sustaining processes. The other characteristic of an ecosystem is its resilience to natural and man-made disturbances through a process called ecological succession (vide supra). The processes which make an ecosystem functioning to sustain life are:

1. Production,

2. Decomposition,

3. Energy flow,

4. Nutrient cycling

The species composition (biotic components) of an ecosystem and its specific climate, soil, and topography (collectively called abiotic factors) forms the structure of an ecosystem. We can understand the structure and function of an ecosystem by taking a pond as an example of an ecosystem.

Pond is a shallow water body which is recognized from its unique structure. We can also observe all above processes running in the pond. The biotic components of the pond are phytoplankton, some algae, free floating, submerged and marginal plants (found at edges) which function as producer species, while fishes, amphibians, and zooplankton function as consumer species. The abiotic components are all inorganic and organic materials dissolved in water and nutrient rich soil deposits at the bottom of the pond. The solar input, the cycle of temperature, day length and species abundance determines the rate of functioning (or rate of above four processes) of a pond. The ecosystem converts inorganic materials to organic molecules with help of solar energy utilizing its all producer species. These organic molecules are used as a source of energy (and also nutrients) by consumer species, so the energy flows from first trophic level (vide supra) to higher trophic level. As the living species of the pond die, the trapped nutrients are released back into the pond through decomposition and nutrient cycling processes with the help of decomposer species of ponds. The decomposers are fungi, bacteria and flagellate which thrive in the bottom of the pond. The energy flows in the pond in a unidirectional manner from lower to higher trophic level and dissipates in the form of heat while all nutrients are cycled again and again. Pond is an example of an aquatic ecosystem, but the same processes could also be observed in a terrestrial ecosystem (Fig. 1). Let's understand the structure and function of ecosystems in detail.

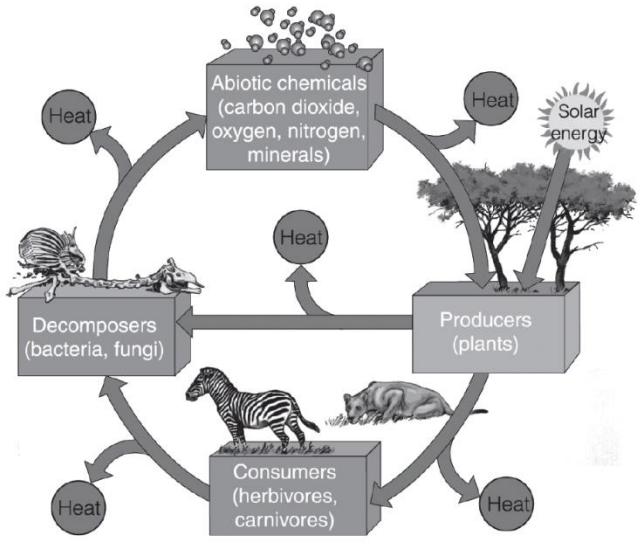


Figure 1. Functioning of the terrestrial ecosystem

4.3 Structure of ecosystem

An ecosystem is made of its biotic and abiotic components confined in a geographical region. The boundary of the ecosystem is sometimes easily recognized as in case of lake, pond, river, but sometimes it is not easily visible such as forests. The boundary of most of the land ecosystems are

defined through its watershed area. Let's have more detailed discussion of biotic and abiotic components making an ecosystem.

Biotic components

For functioning of an ecosystem its biotic components should be composed of following categories of species.

Producer

Producer or autotrophic species are life forms which can synthesize their own food. These could be plants, algae, and photosynthetic bacteria which use solar energy to synthesize their food or chemosynthetic bacteria which use chemical energy of inorganic chemicals (H_2S, CH_4, metal sulfides) to synthesize their food.

Consumers

Consumers are mostly animals which are dependent on producers for energy. Since the consumer species mostly can move they help producer species in pollination and germination.

Decomposers

Decomposers such as fungi, bacteria, earth worm, termites etc. help in disposal of dead animal and plant bodies and their waste products. It is not that they just dispose of waste products, but in the process they also help in recycling of nutrients.

Now we could understand that all above three categories of species should be present for an ecosystem to function.

Abiotic components

The four major abiotic factors of an ecosystem are: temperature, water, light and soil. The quantity and quality of these factors decides the composition of the ecological community or biotic component of an ecosystem.

Temperature

Temperature is the most ecologically significant abiotic factor. Due to the almost spherical shape of Earth and its uneven topography, the temperature of Earth varies from sub zero in polar and high altitude regions to > 50°C in tropical deserts in summer. The thermal tolerance of species decides its distributional range on Earth. Some species (called *Eurythermal*) can tolerate a wide temperature range while others (called *stenothermal*) can survive in a narrow temperature range. It is common knowledge that mango trees cannot be observed in temperate countries like Canada and Germany and snow leopards cannot be found in Western Ghat forest of Kerala. The body temperature of a species is an important physiological parameter as it affects their basal metabolism by increasing and decreasing rate of enzymatic reactions. The mismatch of body temperature from ambient temperature creates thermal stress for a particular species. How species tolerate this mismatch is discussed in the next section.

Water

Water is an important abiotic factor as all the cellular components (bio-molecules) and process are evolved to function inside water. Water is needed by plants for photosynthesis and as part of the circulatory system of animals it helps in distribution of nutrients and removal of waste products from various tissues of the animal body. The scarcity of water in deserts is so high that only species which have adaptation to survive with very low water can be found in deserts. Availability of water on land also affects productivity and distribution of plants. For aquatic species you may think that availability of water is not a problem, but for these species quality of water (pH, salinity, dissolved oxygen etc.) is important. Species which are found in freshwater (lake, river etc.) are different from species that are found in saline water of the ocean. A freshwater aquatic fish or plant cannot survive in a marine environment due to dehydration caused by osmosis.

Light

Light is important as most of the autotrophic species depend on sunlight for making their food through the process of photosynthesis. This food is also the source of energy for all heterotrophic species. In this way sunlight is a source of energy for many ecosystems of Earth. For species which are found at the bottom of dense canopied forest or in deep ocean availability of sunlight is limited. They survive due to specific adaptation in their photosynthetic pathway. Availability of sunlight also affects the temperature of the region. Plant also uses light to meet their photoperiodic

requirement of flowering. Light is also important for animals as their foraging and migratory activity depends on diurnal and seasonal variation of intensity and duration of sunlight.

Soil

Different types of soils are found in different parts of the world. The types of a soil in a region depend on its climate, bedrock, weathering processes and whether soil is transported or sedimentary. Based on soil texture, water holding capacity, pH, mineral composition and depth of a soil, it can support a particular community of plants. Similarly, the sediment composition at bottom of water bodies determines types of benthic animals which can be found in these water bodies. The type of soil in a region determines the vegetation which can thrive in that region. The specific plant community of a region or ecosystem in turn dictates types of animal species which could be observed in the ecosystem.

4.4 Adaptation: Response to abiotic factors

The quality and quantity of abiotic factors in an ecosystem decides types of species which can thrive in the ecosystem. A species is adapted towards available temperature, water, light and nutrients in an ecosystem. These adaptations could be physiological, morphological or behavioral. We could understand these adaptations by taking a few examples.

Adaptation to temperature

In case of habitats in Polar Regions having sub-zero temperature we observe *morphological adaptations* where seals and penguins have smaller limbs and possess a thick layer of fats (blubber) beneath their skin. Few species also survive in extreme temperature conditions by escaping in time and space, if the extreme conditions exist for a limited period in a year. Like polar bears going in hibernation and Siberian birds migrating to warmer regions. These are called *behavioral adaptations*.

Two types of *physiological adaptation* are observed in species to tolerate extreme temperatures. One type is regulation of constant body temperature by physiological processes like perspiration to cool the body in summer and shivering (a type of exercise) which increases body temperature in winter. Species which maintain the constant body environment are highly evolved species like mammals. These are called *warm blooded or regulators*. However, the majority of species (approx. 99%) which include nearly all plants, reptiles, and small birds cannot maintain a constant internal environment; these are called *cold blooded or conformers*. These species tolerate extreme temperature by increasing or decreasing their body temperature as per ambient environment (Fig. 2). This way they minimize the temperature gradient and heat flow from or in the body is stopped. There is also a third category of species (*partial regulators*) which changes their body temperature as per ambient temperature up to some point after that they behave like regulators (Fig. 2).

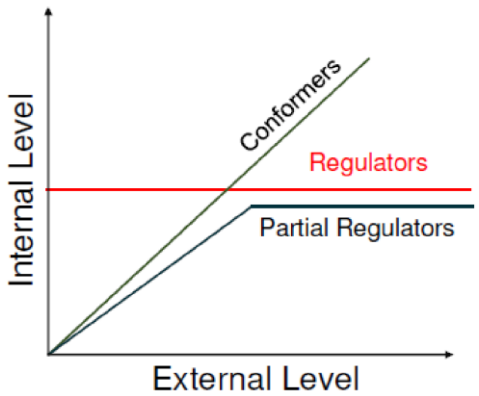


Figure 2. Response of organisms to the external environment (Source: Ref. [2])

Adaptation to water availability

We found many adaptations in desert species which helps them to survive under extreme water scarcity. Kangaroo rats of North American deserts can survive without water for months. They have physiological adaptation of oxidizing their stored fats to generate water which is sufficient for functioning of their body. They also have the ability to concentrate their urine to save water. Desert

[2] Biology: Textbook of Class XII, NCERT (2006).

lizards show behavioral adaptation, they move under shade to save themselves from the high temperature of desert and when their body temperature drops below comfort zone, they bask under sun.

To save water, desert plants either have thick cuticle layers over their leaves or leaves are converted to thorns and photosynthesis are performed by their chlorophyll rich stem as in Cactus and Opuntia.

During millions years of evolutionary periods species have developed adaptations and traits through which they can easily thrive under abiotic factors present in their specific habitat. If these factors are changed due to pollution, climate change, habitat destruction then species cannot survive as in many cases species can tolerate a narrow range of abiotic factors only available in their particular habitat. It is not just species that are adapted to their physical environment, but the ecological community as a whole also contributes to maintaining optimum abiotic factors of the environment which we would discuss in the next unit.

4.5 Functioning of ecosystem

Life is an important characteristic of an ecosystem. To maintain life, four important processes which go on in a functioning ecosystem are: production, decomposition, energy flow and nutrients cycling. Collectively these processes and population interactions (see next unit) provide habitat, food and optimum conditions (abiotic factors) to all species which are part of the ecosystem. Let us discuss these processes in detail in the following sections.

Production

Almost all ecosystems need constant input of solar energy to function and sustain. The solar energy is trapped by autotrophs through the process of photosynthesis. This trapped energy flows through all consumer species. As all living species need energy for growth, reproduction, basal metabolism and movement (in case of animals and other species), we can understand the importance of trapping energy by photosynthetic autotrophs.

The energy available for consumers depends on growth of autotrophs which is measured as primary productivity of the ecosystem. There are two types of primary productivities which we can measure for an ecosystem: Gross primary productivity (GPP) and net primary productivity (NPP). The relationship between the two is:

$NPP = GPP - R$

(1) Where R is respiration losses of producer species (autotrophs).

Net primary productivity is maximum energy which is available to all consumer species. The growth of all consumer species is measured by net secondary productivity which is defined as:

$NSP = B_1 - B_2$

(2) Where B_1 is biomass of all consumer species at time T_1 and B_2 is biomass at time T_2.

The primary production of an ecosystem depends on photosynthetic efficiency of autotrophs, nutrients availability and abiotic factors of the ecosystem. Therefore, primary productivity of different ecosystems varies. The productivity of an ecosystem is similarly defined as:

$NEP = GPP - R_e$

(3) Where NEP is net ecosystem productivity and R_e is net ecosystem respiration. The net ecosystem respiration is defined as:

$R_e = R_a + R_h$

(4) Where R_a is respiration of autotrophs, and R_h is respiration of heterotrophs.

The productivity of an ecosystem is measured in the unit of g m^{-2} yr^{-1} or kJ m^{-2} yr^{-1}, depending on whether we measure it as dry biomass or energy contained in biomass.

Did you know?

The annual net productivity of the whole biosphere is approximately 170 billion tons of organic matter (dry). Out of above 170 billion tons of annual productivity, the oceans contribution is only 55 billion tons, despite occupying 70% of Earth's surface.

Decomposition

Ecosystem is made of a community of living species and similar to human societies a lot of waste is generated in an ecosystem. The waste in the natural ecosystem called detritus is mostly biological in origin and made of dead animal and plant bodies, fallen leaves, twigs, excreta etc. Disposal of this waste is essential to release trapped nutrients back into the environment and mitigating the toxic effects of waste to animals and other species.

Decomposition is performed by detritus feeders or decomposers. The processes involved in decomposition are: 1. Fragmentation, 2. Leaching, 3. Catabolism, 4. Humification, 5. Mineralization. The insects, caterpillar etc. eat up parts of waste material which leads to their fragmentation. The flowing water leached away water soluble minerals from detritus in deep horizons of soil. The enzymes of fungi and bacteria further convert biomolecules of detritus in inorganic compounds in a process called catabolism. The microbial processes convert detritus to humus whose further degradation is very slow. Humus is slowly converted to minerals by some microbes. Humus is a dark colored colloidal matter with rich nutrients content and good water absorbing capacity. It also works as adhesive material and improves soil's texture.

Decomposition is an oxygen requiring process. The rate of decomposition depends on chemical composition of detritus and climatic factors. In particular climatic conditions, the decomposition rate of detritus rich in chitin and lignin is slower, while decomposition rate for detritus rich in nitrogen containing compounds and sugar is faster. The most important climatic factors affecting decomposition are temperature and moisture since they affect activities of soil microbes. Warm and moist climate favors decomposition, while cold and anaerobiosis inhibit decomposition and results in buildup of organic matter.

Flow of energy

Flow of energy is another important process which goes on in an ecosystem. For the majority of ecosystems, the sun is the source of energy. This energy is trapped by plants, algae and photosynthetic bacteria. However, of the whole solar spectrum less than 50% is photo synthetically active radiation (PAR). Of the available PAR on Earth's surface only 2-10% is trapped by photosynthetic producers. Even this energy is sufficient to sustain the whole of the living world. The energy trapped by producers is used by all consumer species. The energy flows through the process of eating and being eaten up which is called the *food chain*. Producers are eaten up by herbivores or primary consumers which are further eaten up by carnivores or secondary consumers, carnivores are eaten up finally by top carnivores, in this way energy flows through a food chain in an ecosystem.

There are two types of food chains which are found in an ecosystem: 1. Grazing food chain (GFC), 2. Detritus food chain (DFC) Grazing food chain starts from live producers, while detritus food chain starts from dead animal or plant matter (Fig. 3). In terrestrial ecosystems more energy flows through DFC than GFC. It is because only a few parts of live plants are eaten up by herbivores and rest energy content of plant body is only available for detritus feeder.

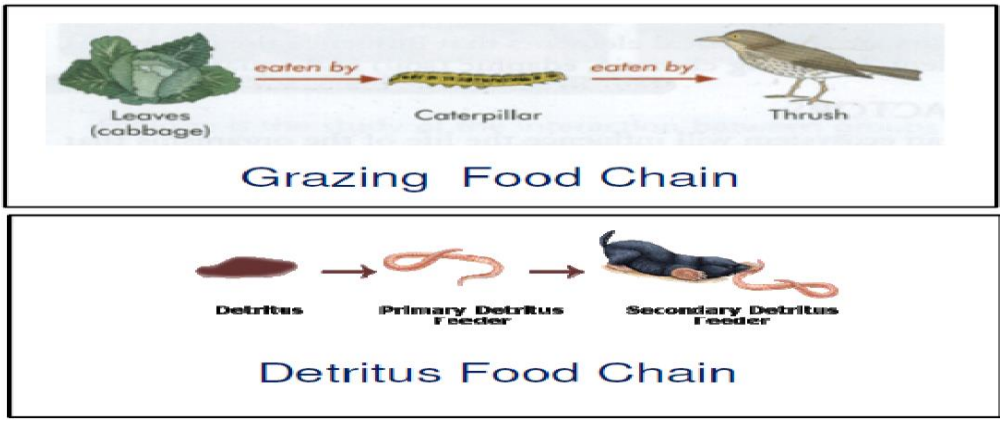


Figure 3. Grazing and detritus food chains

We do not observe simple food chains in an ecosystem, but food chains are connected at many points as a species may also feed on species of other food chains. The interconnected food chains create a *food web* in an ecosystem. Figure 4 shows a food web which is found in the Antarctica ecosystem. The producers of Antarctica Oceans are phytoplankton which are photosynthetic microorganisms living at the surface of oceans. These are eaten up by herbivorous zooplanktons

which are food for squid fish which is further eaten up by elephant seals and elephant seals are prey of small toothed whales. Phytoplanktons are also eaten up by krill which is food for many higher consumers such as leopard seals, sea birds, baleen whales etc. The krill is the intersection point of many food chains of Antarctica Ocean.

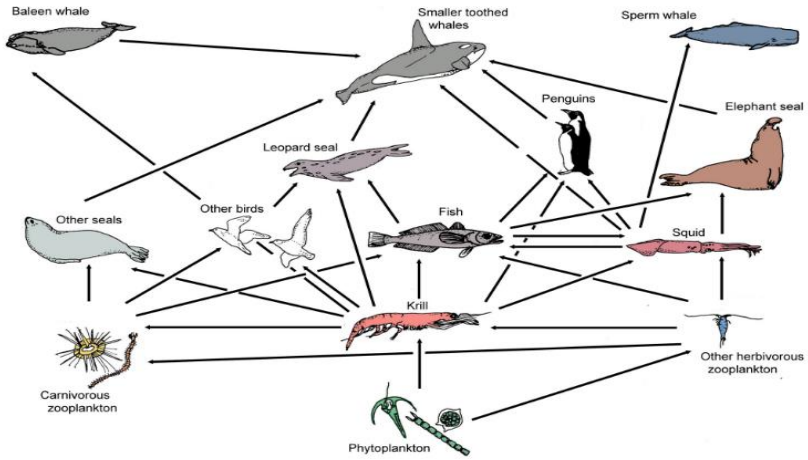


Figure 4. Food web of Antarctic Ocean (Source: Cool Antarctica)

Flow of energy through the food chain follows two fundamental laws of thermodynamics: First law of thermodynamics and second law of thermodynamics. A general rule of thumb (called 10% Law) for flow of energy through the food chain is: On average only 10% energy contained in a given trophic level (position of species in a food chain) is transferred to higher trophic level. The 10 percent law of energy flow in the food chain satisfies the first law of thermodynamics (conservation of energy); as 90% of energy is lost during respiration of species of lower trophic level to sustain its vital processes. The ten per cent is in accordance with second law of thermodynamics no energy conversion process is 100% efficient, in case of conversion of chemical energy content of a species to energy content of species of higher trophic level is just 10% (Fig. 5).

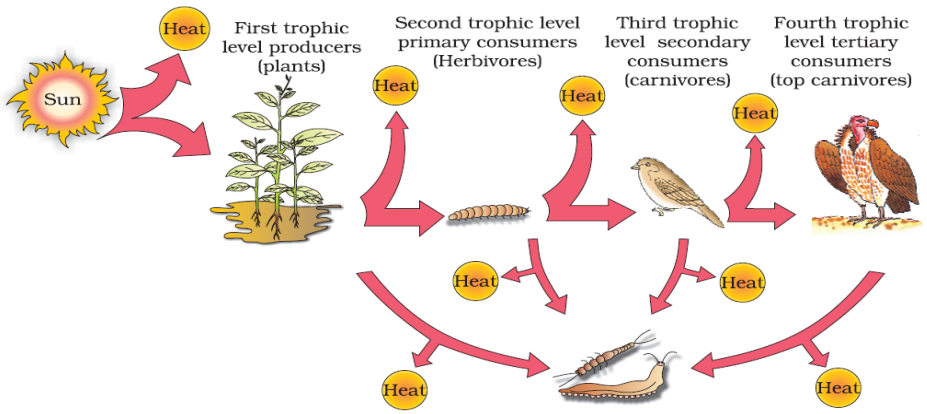


Figure5. Flow of energy through the food chain (Source: Ref. 2 NCERT…)

Food web shows us interactions of various species to other species of an ecosystem. *It helps us in analyzing the impact of population changes of one species to other species and on the whole ecosystem.*

4.6 Ecological pyramid

The position of a species in a food chain is known as its trophic level. If we plot number of species or their biomass or energy contained in all species at given trophic level against all trophic level present in an ecosystem, we generally get a pyramidal relationship which are called ecological pyramid. Based on parameter used these pyramid are called pyramid of number, pyramid of biomass and pyramid of energy. Pyramid shape (a shape with wider base which narrows down at apex) relationship can only be obtained if we consider all species present at different trophic level in an ecosystem.

Pyramid of number

Pyramid of number is graphical representation of number of species at different trophic levels of an ecosystem. For most of the terrestrial ecosystem we got an upright pyramid of numbers. Figure 6 shows the pyramid of numbers for the grassland ecosystem. We can see that to support three top carnivores we need almost 6 million plants.

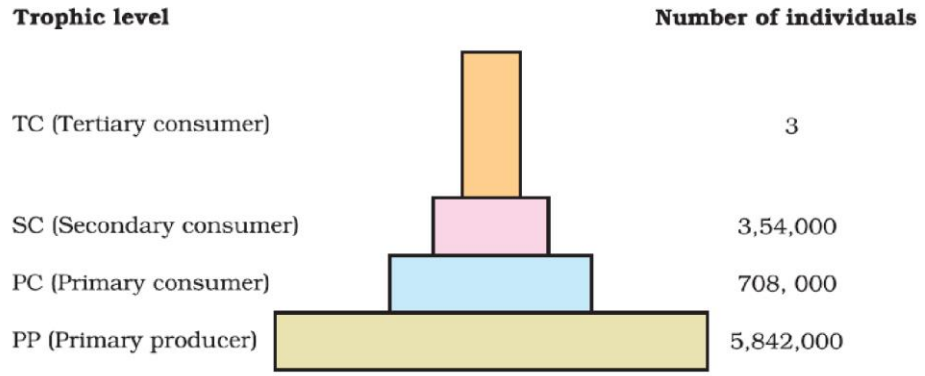
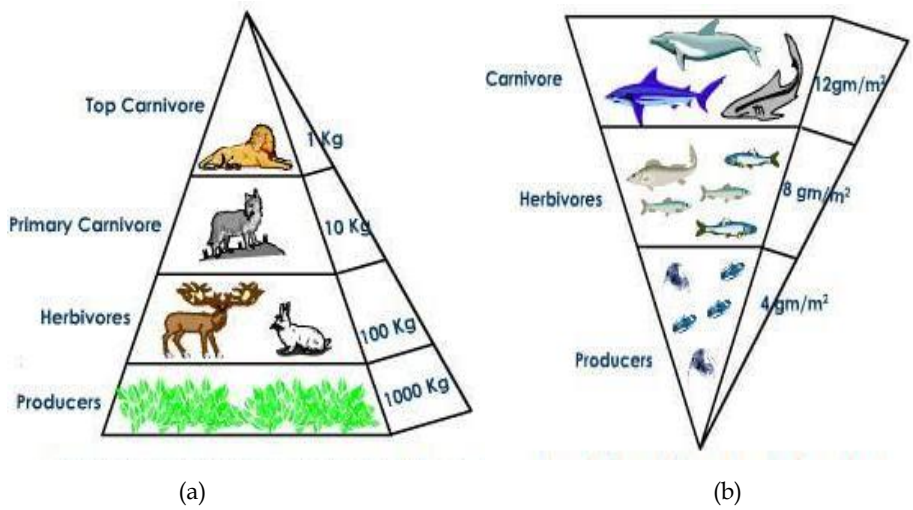


Figure 6. Pyramid of grassland ecosystem. (Source: Ref. 2 NCERT….)

Pyramid of biomass

Pyramid of biomass is graphical representation of total biomass of all species at different trophic levels. The biomass or number of all living species at a given trophic level at a particular time is called *standing crop*. It is measured as the number or biomass of all living species per unit area. Pyramids of biomass are mostly made using standing crops at different trophic levels. Pyramids of biomass for land based ecosystems are always found up right (Fig. 7a), which is plausible according to 10% law... However, the pyramid of biomass of aquatic ecosystems (lakes, marine ecosystem etc.) is of inverted type (Fig. 7b).



(a) (b)

Figure 7. Idealized pyramid of biomass of grassland and aquatic ecosystem

As we can see in figure 7b, just 4 g/m² biomass of producers can support just double biomass (8 g/m²) of consumers at the next level. You can also verify it by weighing dry biomass of all algae and aquatic plants of a lake and dry biomass of all herbivorous fishes. Most probable you might find the biomass of all live algae less than biomass of herbivorous fishes. Though the biomass of algae in an ecosystem is less than herbivorous fishes at a given point of time, high reproduction rate of algae can support large biomass of the fishes which have longer life span.

The pyramid of energy is a graphical representation of the energy content of different trophic levels. This pyramid of energy always remains upright since consumer species cannot have more energy than trapped by producer species. It approximately follows 10% Law of Energy and always is of upright shape (Fig. 8).

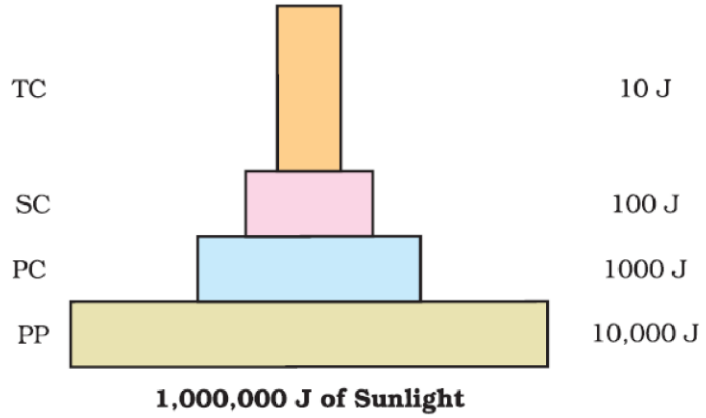


Figure 8. An ideal pyramid of energy

Pyramid of energy explains why the number of top carnivores in the terrestrial ecosystem is always the least as the available energy needed by species of highest trophic level is least.

Ecological succession

An important characteristic of the ecosystem is resilience to natural and man-made disturbances. A healthy and undisturbed ecosystem maintains a fairly constant composition and abundance of species which are in equilibrium with its physical environment. A disturbance such as forest fire, flood, drought or man-made destruction can change the composition and abundance of species, but the degraded ecosystem can revert back to its original state through a process called *ecological succession*.

Ecological succession is a fairly predictable sequential change of species composition of an ecosystem. The change continues till the establishment of *climax community*. The species appearing just after disturbance are called *pioneer species*. The intermediate communities are called *serial communities*. Ecological succession is of two types: Primary succession and secondary succession. Primary succession occurs in areas where no species existed before, while secondary succession occurs in areas which lost their biota due to natural or human induced disturbance. Secondary succession occurs at a faster pace since soil, water. Primary succession which occurs on freshly created land formed by cooling of lava or cut rock or newly created ponds takes several hundred to thousands of years since formation of soil with sufficient nutrient and depth is a slow process which provides medium for germination of pioneer species.

The succession of plant communities during ecological succession creates optimum conditions and habitat for animal species and also changes composition of animal species. The succession of plant communities is *hydrarch succession* if it happens in wetter areas and *xerarch succession* if it occurs in dry areas. The succession converts the initial habitat (wetter or very dry) finally to mesic (medium water) habitat.

Let us discuss primary ecological succession (xerarch succession) over fleshly created dry rocks. Since on rock there is no soil, the pioneer species mostly are lichens which need very small amounts of soil available between cracks of rock. Lichens secrete acid which dissolve rock and create more soil. As soil amount increases it creates habitat for small plants like bryophytes such as mosses. Mosses and lichens both survive under very dry conditions by going dormant. Mosses further trap flowing and blowing soil particles by acting as a sieve. The mat of moss and soil provide a base for germination of larger plants. These larger plants further increase the depth of soil and paves the way for shrubs and trees. The litter generated by big trees covers the soil surface and leads to the decline of moss and smaller plant populations. Thus a gradual change of species composition occurs during primary succession on freshly created dry rocky land.

Major biomes

Almost spherical shape of our Earth and tilt of its axis of rotation creates various climatic zones on Earth. The climate of a region is characterized by its average temperature and average precipitation. Similar climatic zones of Earth support broadly similar biological communities due to similar temperature and water availability. The similar climatic zones of continents and its associated biological community are called *biomes* of Earth. Aquatic areas are likewise classified based on temperature and availability of light, but the term biome is only used for terrestrial habitats.

According to average temperature and precipitation there are six major biomes: tropical forests, grasslands, temperate forests, coniferous forests, Arctic and alpine tundra, and deserts (Fig. 9).

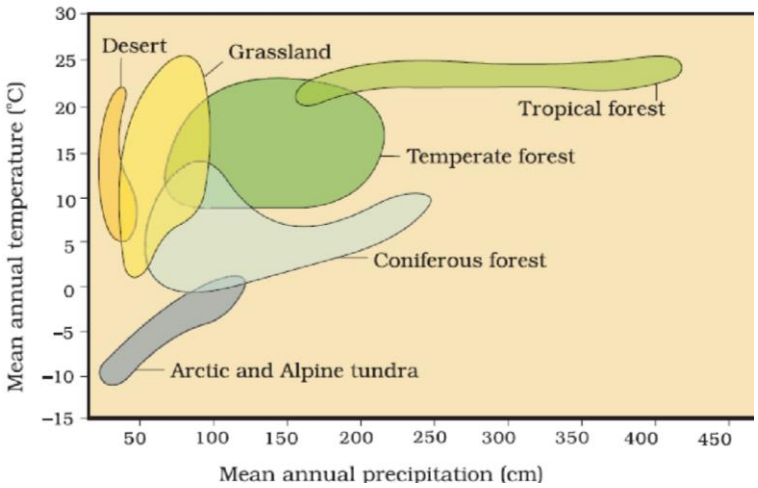


Figure 9. Biome of Earth as defined by mean annual temperature and precipitation (Source: Ref. 2)

As explained in figure 9, average precipitation is major climatic factor to decide whether a region will support a forest, grassland or desert. Tropical forests are found in region which receives frequent and heavy rainfall (on average 240 cm/yr) and almost no seasonal variation with average temperature around 28°C. Tropical forests are found in South and Central America, islands of Indian and Pacific Oceans and Southeast Asia. Temperate or deciduous forests are found in areas which receive less rainfall (76-203 cm/yr) than tropical forests and exhibit various seasons in a year (summer, monsoon, winter). Coniferous forests are found in coldest parts of world. They also have seasonal climates with longer winters and mostly dominated by coniferous forests.

4.7 Forest

As explained above, forests are found in areas with high rainfall. The different types of forest found in our country are: Himalayan coniferous forests, Himalayan broad leaved forests, deciduous forest, evergreen forest, thorny forests and mangrove forests. Let us understand the forest ecosystem by taking the example of Western Ghat forest in India.

Western Ghat forest

Western Ghats are a chain of mountains running parallel to western coast of India. Due to this topography they interrupt most of the South-West monsoon which results in average rainfall of 250 cm/yr with a very short dry season. Further coastal vicinity and closeness to the equator provide a near constant temperature of more than 18°C. This climate allowed the evolution of rich diversity of evergreen trees, plant and animal species in this forest. The major tree species are Jamun, Ficus and Dipterocarpus. The continuous overlapping of trees forms a canopy, which obstructs the light to reach forest's floor (Fig. 10). Only shade loving shrubs and creepers grow below the canopy of big trees. The bark of the trees is mostly covered with mosses. Western Ghats are ranked eighth in richness of biodiversity and are characterized with high levels of endemism (See unit 5). Few endemic and common animal species of Western Ghats are: Lion-tailed macaque, Pygmy hog, and Malabar pied hornbill.

Figure 10. Western Ghats' forest

Grassland

Grasslands are found in regions with annual rainfall around 25-120 cm/yr. Due to poor rainfall these areas only support the grasses, scrub and herbs. Dry grassland often suffers frequent fire. These grasses support grazing animals (bison, deer etc.), lions, insets, reptiles, termites etc. Different grasslands which are part of our country are: Himalayan pasture land, Terai, Semi arid plains of Central India, Deccan plateau and Shola grassland.

Terai grassland

Terai is grassland which runs along the foothills of the southern side of Himalaya where Himalayan Rivers touch the plain. The grassland is characterized by tall elephant grasses with height up to 5 meter. This grassland interspersed with Sal forests where elevation is high. The Terai arc also includes marshes in low lying areas. The Terai arc extends from Corbett national park in the West to Kaziranga national park in the East spanning India, Nepal, and Bhutan. The major animals supported by Terai grassland are: Rhinoceros, elephant, tiger, water buffalo, and swamp deer (Fig. 11). It is clear from the above discussion that rainfall is major factor in deciding dominant vegetation of an ecosystem since high altitude regions of Himalaya receives major rainfall creating a rain shadow type zone in the foot hill resulting in grassland, while high elevation zone in same arc support Sal forest.

Figure 11. Kaziranga national park (part of Terai)

Desert

Desserts are found in areas which receive rainfall less than 25 cm/yr. Due to thin and porous soil desert ecosystems are highly fragile. The very less availability of water in the desert only supports xerophytic plant species such as horny bushes, shrub and cacti. Dominant life forms of desert are: rodents, lizards, snakes, hawks and birds. They won't support a high population of big herbivores. Deserts found in India are: Thar Desert, Cold desert of Ladakh and The Great and Little Rann of Kutch.

Case Study: Thar Desert

Thar Desert spreads in Jaisalmer and Barmer district of Rajasthan. The Aravali hills make its eastern most boundaries while western boundaries are made by fertile plains of the Indus. Northern boundary is made by riparian plains of sub-Himalaya and in the south it is contained by The Great

Rann of Kutch. The region receives scanty and sporadic rainfall and in some areas it rains once in a few years. This climate supports thorny forest type of vegetation. The landscape is dominated by a vast spread of sand, sand dunes and broken rock formations with sparse vegetation and open grassland (Fig. 12). Khejri is one of the important trees of the Thar Desert which is used for fodder, fuel wood and its edible pods. Due to its immense importance in survival of the human community in the harsh environment of Thar Desert, the tree is revered and sacred by many communities of desert especially Bishnois. Other important tree species of the Thar Desert are Babul, Rohida. Thorny trees have small leaves (with many having thick cuticle layers on leaves) and more thrones which help them to save water. These trees also have long hairy roots which extend too much depth in soil for absorbing soil moisture. The desert grass goes dormant during drought years and grows when it rains.

Desert is rich in reptiles. Of all reported reptile species 11% are found in the desert and many are endemic to the Thar Desert. The important mammals of Thar are: camel, chinkara, desert fox, desert cat etc. The important bird species of desert are Great Indian Bustard, partridge, quail, sand grouse and white backed vultures. Desert animals are specially adapted to low water conditions and have the ability to store a lot of fat which helps them survive in dry areas. (Ref.[3])

Figure 12. Thar Desert of India

4.8 Aquatic ecosystem

Aquatic ecosystems are water based ecosystems composed of aquatic plants and animal communities. Based on salinity of water aquatic ecosystems are of three major types: 1. Freshwater ecosystems, 2. Marine ecosystems, 3. brackish ecosystems.

There are two subtypes of freshwater ecosystem: 1. Lotic or running water ecosystem (river and streams), 2. Lentic or still water ecosystems (ponds, lakes and wetlands), Marine ecosystems also have two subtypes: 1. Coastal shallows, 2. Deep oceans. Coral reef is an important coastal shallow aquatic ecosystem found mostly in tropical waters which is second in richness of biodiversity. Brackish water ecosystems also have two subtypes: 1. Delta, 2. Lagoon.

The richest coral reef ecosystems of our country are found at Andaman and Nicobar Island and the Gulf of Kutch. The important brackish water ecosystem of India is Ganga river delta of Sunderban. This brackish water ecosystem or swamp is covered with mangrove forest. Mangrove forests are the most productive ecosystem of the world in terms of biomass production. The important lagoon ecosystem of India is Chilika Lake. Let us understand this ecosystem in detail.

Chilika Lake

Chilika Lake is a shallow water lagoon at Eastern Coast of India (Fig. 13). It is a pear shaped lagoon having length of 64.5 km and width varies from 5 to 18 km. The lagoon spans Puri, Khurda and Ganjam districts of Odisha state of India. The lagoon was created by silting action of river Mahanadi which drained to lake from its northern side and northerly sea currents of Bay of Bengal which created a sandbar to convert an estuary in the lagoon lake. The lake is divided in two parts: a

[3] UNESCO, https://whc.unesco.org/en/tentativelists/5896/ Accessed on May-2021.

narrow outer channel which provides an outlet for the lake to Bay of Bengal and the main body of lake. This unique topography of lake provides a stable environment undisturbed from tidal currents, stable salinity gradient, and well mixed water column due to extreme shallowness of lake and wind action which bring nutrient rich bottom sediments to surface.

The producer species of lake are phytoplankton, benthic and epiphytic algae, and water weed Potamogeton pectinatus. The high temperature (15-26°C) of lake and salinity (5000 – 11,000 ppm) increases the rate of decomposition process of detritus and fastens the nutrient cycle. The fast nutrient cycle in combination with high nutrient input from land drainage, makes the lake a high productivity ecosystem. The presence of different salinity zones in the lake increases the richness of faunal diversity of the lake as both marine and riverine fishes and other species use the lake as habitat. Nalaban island which is submerged in four of five monsoon months emerges as marsh in the month of October and attracts a rich population of migratory birds (around 150 bird species) especially waterfowl, ducks, geese, flamingos etc. Some rare species like dolphin and limbless skink are also found in the Chilika Lake. (Ref.[4])

Figure 13. Chilika Lake: Lagoon ecosystem

Summary

Ecosystems are essential for sustaining life of all living species found on Earth. These are functional units of Nature made up of interaction of communities of species among themselves and with their physical environment in a geographical region. A population of species cannot survive in isolation and sustaining life is an important characteristic of the ecosystem. Ecosystems sustain life due to interaction within a community of species (biotic component of ecosystem) which are adapted to climate, soil, light availability (abiotic components) of a geographical region and due to running of four important processes. The boundary of the ecosystem is sometimes easily recognizable like for pond or river ecosystems but not so easily visible for terrestrial ecosystems. For terrestrial ecosystems like forests and grassland we mostly take the watershed of the terrestrial ecosystem as its boundary. The structure of the ecosystem is specified by its biotic and abiotic components. The living members of an ecosystem are not only adapted to its abiotic components but also contribute in maintaining favorable abiotic factors of their ecosystem. As all living species of the ecosystem have a life cycle, functioning of the ecosystem (to sustain life) needs continuous running of four processes. These are: production, decomposition, energy flow and nutrient cycling. Birth and

[4] Chilika Lake Development Authority, http://www.chilika.com/environments.php Accessed on May-2021.
[5] Wright, R. T.; Boorse, D. F. Environmental Science: Towards Sustainable Future, 12e, Pearson, India (2015).
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growth of new living species in an ecosystem is called its production, production removes a lot of nutrients available from the ecosystem and after death of these species the trapped nutrients are released back to the ecosystem through the process of decomposition and nutrient cycling. Since living species need a constant supply of energy (in form of food), the energy to the ecosystem is supplied mostly by the Sun. The solar energy is trapped by producers (autotrophs) which move to consumers (heterotrophs) through energy flow. The flow of energy creates food chains and food webs in an ecosystem. The flow of energy in an ecosystem generally follows ten percent law i.e. only 10% (approx.) energy contained in lower trophic can only transfer to higher trophic level. This law results in pyramid-like patterns of species composition in ecosystems called ecological pyramids. A healthy ecosystem can restore itself after man-made or natural disturbance through a fairly predictable sequence of change of species composition called ecological succession. Based on two important abiotic factors (average temperature and average precipitation) we observe important biomes on our Earth such as forests, grassland, desert etc. Western Ghats of India supports the tropical forest ecosystem. An example of a major desert of India is Thar Desert, while Terai is prominent grassland of India. Above examples of land based ecosystems of our country clearly explains how abiotic components decide the ecological community of an ecosystem. There are three major aquatic ecosystems on Earth: freshwater ecosystems, brackish water ecosystems and marine ecosystems. Chilika Lake (lagoon) is India's highly productive brackish water ecosystem.

Keywords

Ecology, Ecosystem, Adaptation, Productivity of ecosystem, Decomposition, Autotrophs, Heterotrophs, Energy flow, Food chain, Food web, Ecological pyramid, Ten percent law, Nutrient cycling, Ecosystem functioning, Ecological succession, Biomes, Forests, Grassland, Desert, Freshwater ecosystem, Brackish ecosystem, Marine ecosystem, Thar Desert, Western Ghats' forest, Chilika Lake

Self Assessment

1. Ecology is a biology subject which study_____

A. Function of cell at molecular level
B. Functioning of human cardiovascular system
C. Interaction between communities of different species
D. Microbial organism

2. Branch of ecology which study factors affecting population of a species is called_____

A. Ecosystem ecology
B. Restoration ecology
C. Physiological ecology
D. Population ecology

3. Decomposers are species which_____

A. Synthesize their own food
B. Depends on live producer for food
C. Depends on live animals for food
D. Depends on dead plants and animals for food

4. Which of the following is an abiotic factor of an ecosystem?

A. Light
B. Producer
C. Decomposer
D. Consumer

5. The body temperature of regulators (warm blooded) animals_____

A. Remains constant
B. Changes with external temperature

C. Changes till some value of external temperature and then becomes constant
D. Can increase to ignition point

6. Hibernation of polar bear during winter of Arctic is an example of_____

A. Physiological adaptation
B. Behavioral adaptation
C. Morphological adaptation
D. Cloning

7. Process of eating and being eaten up is called_____

A. Production
B. Decomposition
C. Food chain
D. Food web

8. Detritus food chain starts from_____

A. Live plants
B. Live animals
C. Dead animals and plant and bio-waste
D. Minerals

9. Food web is made of_____

A. Many non-connected food chains
B. Interconnected food chains
C. Web of trees
D. Web formed by tropical spiders

10. Only_____ energy flows from one trophic level to the next higher trophic level.

a) 90%
b) 99%
c) 10%
d) 1%

11. Trophic level tells us position of species in_____

A. Animal society
B. Food chain
C. Terms of quality
D. Terms of strength

12. Pyramid of energy is an ecological pyramid which graphically represent_____ at different trophic levels.

A. Biomass
B. Number of species
C. Energy content
D. Biomass and number of species

13. Number of top carnivore in a grassland ecosystem is always found lowest since_____

A. Illegal poaching
B. Flow of energy follows 10% law
C. Energy remains conserved
D. Climatic conditions do not favor population growth

14. Tropical forests are found in regions which receives_____ average rainfall.

A. Very high
B. Poor
C. Moderate
D. No

15. _____is one of the important trees of the Thar Desert.

A. Pine trees
B. Mango trees
C. Teak
D. Khejari

16. Which of the following aquatic ecosystems possess the richest biodiversity?

A. Lakes
B. Coral reefs
C. Ponds
D. River

Answer for Self Assessment

1.	C	2.	D	3.	D	4.	A	5.	A
6.	B	7.	C	8.	C	9.	B	10.	C
11.	B	12.	C	13.	B	14.	A	15	D
16.	B								

Review questions

1. What is ecology? Explain its various branches.
2. What do you mean by the structure of the ecosystem?
3. What is adaptation? Explain with examples.
4. Explain production and decomposition processes of the ecosystem.
5. Explain various laws which govern flow of energy in an ecosystem.
6. What is food chain and food web? Discuss giving one example.
7. Discuss functioning of the ecosystem with one example.
8. What is ecological succession? Explain primary ecological succession with one example.
9. How biotic and abiotic components of ecosystems interact with each other? Explain taking examples of Western Ghats ecosystem.
10. How many types of aquatic ecosystems exist on Earth?
11. Discuss Chilika Lake ecosystem with respect to interaction between biotic and abiotic components.

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Unit 05: Levels of Biological Diversity

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Objectives

After completion of this chapter you will be able to

- understand what biodiversity is.
- define what is genetic and species diversity.
- know about ecosystem diversity of India.
- know why our Earth has enormous biodiversity.
- know the biogeographic zones of India.
- understand the pattern of variation of biodiversity.
- know global biodiversity hotspots and hotspots of biodiversity of India.
- know the position of India in the world in terms of biodiversity richness.
- know endangered and endemic species of India.

Introduction

Ecosystem supports a rich and unique combination of species called the ecological community. The ecological community of an ecosystem is decided by the combination of abiotic factors making an ecosystem (as explained in the previous chapter). In this chapter, we would understand the causes which led to rich biodiversity of our planet. Before going on to find reasons behind the rich biodiversity of our Earth, we would first learn what do we mean by biodiversity? Then we would learn how science of taxonomy helps us in understanding the vast species diversity of our Earth and how we can recognize and name a species. Next, we would focus on the role of evolution and Earth's climate in creation of various biogeographic realms and zones of the world including creating hotspots of biodiversity. The discussion would also explain why our Earth possesses rich biodiversity. Further, it would assist us in understanding biogeographic zones of India and the status of India in the world in richness of biodiversity including endemic species of India. Finally,

we would also learn about endangered species of India. The reason why many species of our country are becoming endangered is a matter of discussion in the next chapter.

5.1 What is Biodiversity?

Earth is the only known planet in the universe where someone can find a huge diversity of life. If we just talk about common life forms around us then it may surprise us that there are 20,000 species of ants, 3, 00,000 species of beetles and 28,000 species of fishes. The diversity of life on Earth is called biodiversity. Biodiversity is just not different species which we can find in a given region, biodiversity could be found at all levels of biological organization from macromolecules to biome. Biodiversity is a term which was first used by Edward Wilson to describe diversity at all levels of organization. However, the three most important levels of biodiversity are: genetic diversity, species diversity and ecological or ecosystem diversity.

Genetic diversity

We can find different genetic variants of a species in its distributional range. The genetic variants may be different with respect to particular traits of a species such as concentration of active compound (reserving) in different genetic variants of medicinal plant *Rauwolfial vomitoria* found in different ranges of Himalaya. We can find more than 50,000 genetically different strains of rice plant and approximately 1000 varieties (genetic variants) of mango in India. Maintenance of the genetic pool is essential for healthy breeding of the population of species.

Species diversity

Different types of species (plants, animals and microbes) which could be found in geographical regions or political entities constitute its species diversity. Western Ghats of India have greater species diversity of amphibians than Eastern Ghats.

Ecological or ecosystem diversity

Number of different ecosystems which could be found in a country or political entity constitutes its ecosystem diversity. India with its desert, rain forests, mangroves, wetlands, coral reef, alpine meadows has greater ecosystem diversity than countries like Norway.

5.2 Biodiversity: Hierarchical Arrangement

There are around 1.5 million species recorded by IUCN (International Union of Conservation of Nature) till 2004. However, most recent estimates suggest around 8.7 ± 1.3 million species may exist on Earth. The inventory of various taxonomic groups of species is more complete in temperate countries, but in tropical countries we are still coming with new species. The question is how we classify and recognize a species from the millions of species which exist on Earth. The science of classification of species is called *Taxonomy*.

In taxonomy we classify species based on their evolutionary relationship. A species is a group of very similar organisms that share certain characteristics not found in other such group and mostly interbreed among themselves. The group of closely related species is called *genus*. Such as tiger, loin and leopard are in one genus known as *Panthera*, potato and brinjal are grouped together in genus *Solanum*. The genera in turn are grouped in *families* such as genus *Panthera* and genus of all cats *Felis* are grouped in one family called Felidae. The group of similar families is called *order*, which in turn is grouped in *class*. Class forms the next higher order called *phylum* and finally phyla makes the kingdom of species (Figure 1).

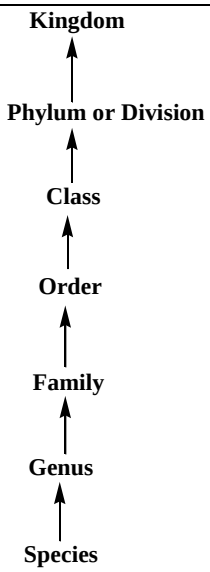

Figure1. Hierarchical order of biodiversity showing various taxonomic categories (Source: Ref. 1)

There are five kingdoms of species: Animalia (comprising all animals), Plantae (all plants), Fungi, Protista, Monera (bacteria). The various hierarchical categories of species classification are called taxon (pl. taxa). As we move from species to higher taxa similarity between species is declined. The biological or scientific name of a species is made of two words: the first word denotes its genus and the second word is epithet of a particular species. For example, the biological name of humans is *Homo sapiens*, where *homo* is a genus of human which also includes extinct species such as *Homo erectus*, Neanderthal etc. Biological names are mostly in Latin and written in italics. Table 1 shows biological names and taxonomic categories of a few common species.

There are some interesting facts about Earth's rich biodiversity. Of all recorded species, 70% are animals and 22% are plants (including algae, fungi, bryophyte, angiosperm, and gymnosperm). Of all animal species more than 70% are insects. The number of fungi species is more than the combined total of fishes, amphibians, reptiles and mammals (Fig. 2). It is difficult to identify the number of prokaryotes as conventional taxonomic methods are not helpful, but if we use molecular criteria for delineating a species then their number alone can be in millions.

Table1. Biological names of common species and their taxonomic categories (Source: Ref. 2)

Common Name	Biological Name	Genus	Family	Phylum/ Division
Man	*Homo Sapiens*	Homo	Hominidae	Chordata
Housefly	*Musca domestica*	Musca	Muscidae	Arthropoda
Mango	*Mangifera indica*	Mangifera	Anacardiaceae	Angiospermae
Wheat	*Triticum aestivum*	Triticum	Poaceae	Angiospermae

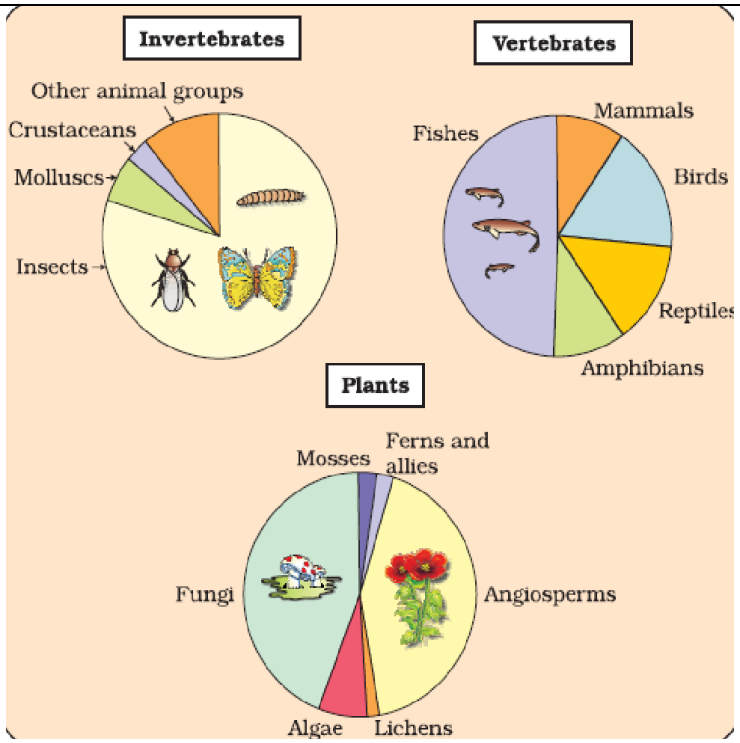

Figure2. The global biodiversity: Representing relative abundances of species of major taxa of plant, vertebrate and invertebrate. (Source: Ref. 2)

Why are there so many species?

Life evolved on Earth from a single cell to a current diverse variety of life forms including humans. This happens due to plate tectonics of Earth which created many diverse habitats with varied niches having different combinations of abiotic factors which in turn resulted in abiotic pressure on ancestral species. In addition to selective pressure from abiotic factors, biotic factors (competitive exclusion, symbiosis, predation and parasitism) also exerted selective pressure on species. The selective pressure (biotic and abiotic) on preexisting species gets combined with naturally occurring constant variation of genetic material (mutation, genetic drift and gene flow) of the species which results in evolution of new species or speciation.

Let us understand various processes involved in biological evolution and how biotic factors and continental drift induced abiotic factors resulted in generating current biodiversity of Earth.

Biological evolution

In addition to reproduction, biological evolution is another characteristic which separates life from other things of the universe. As per theory of biological evolution, a new species forms as a result of competition for resources and ability among individuals to adapt to environmental conditions. The processes involved in biological evolution are: mutations, natural selection, genetic drift and gene flow.

Mutation

Genes are part of chromosomes within the nucleus of a cell which are inherited from one generation to the next generation. Genes are actually DNA (deoxyribonucleic acid) molecules which is a biopolymer made of a combination of four nucleobases: adenine a, cytosine C, guanine G and thymine T. The base pairs remained in paired forms in a double stranded structure of DNA. A gene is a fragment of DNA, which has a unique combination of four nucleobases which could be read by the cell's transcription and translation machinery to prepare a corresponding cellular bio-molecule.

DNA is replicated during cell division and copy of DNA is transferred to daughter cells from the parent cell. However, during replication of DNA sometimes error happens (caused by radiations,

mutagens etc. or random error), this leads to change in base-pair sequence in daughter cells from parent cell, a process called *mutation*.

Mutation could either impair the survival of cells (or offspring) or it could just add variability to the inherited characteristics. A group or individual which has specific genetic makeup is called *genotype*.

Natural selection

Natural selection is the process by which the population of a genotype in a heterogeneous population increases in comparison to other genotypes due to changes in environment. The changing environment creates selective pressure on survival or reproduction ability of a species. Now due to genetic heterogeneity of population (mostly caused by mutations), some individuals may have better traits to survive under pressure induced by changing environments. The proportion of offspring of individuals which are more fit to changing environments will increase in future generations of the species.

When a natural selection occurs over a long period of time, the changes in characteristics of species could be so large that species can no longer reproduce with individuals having DNA structure that was present before change in environment started. This way natural selection leads to formation of new species.

Genetic drift

The sudden isolation of a small group from a larger population leads to huge changes in frequency of genes (actually the different variants of a gene or allele) in isolated groups from larger populations. The genetic drift generally decreases species chances to adapt to changing environments through natural selection due to lack of allele which is needed to provide a favorable trait in small populations.

Gene flow

Gene flow is movement of genes into and out of the population through migration in animals and dispersal of pollen in plants. Gene flow can bring the new version of a gene to a population which is devoid of that gene.

There are no simple rules which can predict a species to adapt to changing environmental conditions or it will go extinct. A species could adapt to a level of generation of new species or just fail to adapt to a changing environment is simply unpredictable. Evolution is still a game of chance for us.

5.3 Continental Drift: Geographic Isolation and Migration

According to the theory of plate tectonics, the continents of Earth join together and then separate from each other periodically. This happens due to movement of major tectonic plates of Earth's crust over molten magma of the mantle. If we look at the 4.6 billion years old history of Earth, then life originated on Earth some 3.5 billion years ago in the form of a unicellular microorganism called Archaea. These microorganisms stayed on Earth till the next 2 billion years. The major change came after the evolution of photosynthetic bacteria which filled Earth's atmosphere with oxygen. The high concentration of oxygen in the atmosphere created a new ecological stage for evolution of oxygen breathing organisms. The first multi cellular organisms appeared on Earth some 600 million years ago.

The biggest evolution event occurred during the Cambrian period which lasted around 500 million years ago. Cambrian explosion produced many of current animal taxa such as arthropods, chordates etc. (Fig. 3). However, still all Cambrian animals were marine aquatic animals. Almost 100 million years later, in the Silurian period plants evolved to survive on land. First amphibians emerged in the Devonian period (417-363 million years ago). Amphibians finally evolved to reptiles. Reptiles resulted in evolution of two orders of dinosaurs (the largest quadrupeds ever found on Earth) in the Triassic period which started some 245 million years ago.

Figure3. The Cambrian period: Explosion of evolution. (Source: Ref. 3)

However, some 225 years ago all continents of Earth were part of a large landmass called Pangaea. This land mass resulted in the spread of all evolving terrestrial animals and plants on all continents through the process of migration and dispersal. Tectonic movements started to break this Pangaea around the same time and continents drifted from each other at a rate of 6 cm/yr. The separation of continents and emergence of new mountain ranges separated and isolated many evolved animals, plants and other species and moved them to new climatic and environmental conditions. The geologic processes and migration (and dispersal) placed the evolved species under different abiotic factors which exerted selective pressure on these species for survival. These factors were different bedrock, soil, climate and elevation. The abiotic factors first affected the evolution of vegetation which in turn affected the evolution of animal species. The process of natural selection over a long period of time in the geographically isolated original population resulted in so much change in genetic makeup of two populations of species that they cannot reproduce if they interbreed somehow by migrating to habitat of other species or we can say the two new species have formed. The phenomenon of formation of two new species from original ancestral species is called speciation.

The continental drift induced geographical isolation created convergent and divergent evolution of species. *Divergent evolution* happened when the same ancestral population occupied a different ecological niche (Fig. 4) and *convergent evolution* happened when different ancestral populations occupied similar ecological niches (vide supra). Based on the similarity of ancestral species of animal and plant, we can divide the whole world in different *biogeographic realms*. Biogeographic realms are also called Wallace realms as they were first recognized by British biologist Alfred Russell Wallace in 1876. We shall discuss Wallace's realm in more detail soon. Now, let us understand how biotic factors contribute to speciation.

Figure4. Divergent evolution of New World's rat snakes: Ecological opportunity triggers adaptive radiation. (Source: Ref. 4)

5.4 Biotic Factors and Speciation

The interaction of a species with other species in new habitat, further exert biotic pressure on the species towards adaptation or speciation. Fundamentally, three types of interaction occur between two species: completion which affects both species in negative manner, symbiosis where both species are affected in positive manner, and predation-parasitism where one species (predator/parasite) is in gain while other species (prey/host) in loss.

The competitive principle of exclusion states that two species depending on identical resources and habitats cannot coexist. As per this principle there should be some 400 species on Earth for around 100 climatic conditions (one producer, one herbivore, one carnivore, one decomposer per climatic condition), but there are more than 1.5 million species till now recorded. One of the causes of so much diversification is the 'principle of competitive exclusion' required that for coexistence species should be adapted to slightly different ecological niches.

Ecological niche is defined as a set of all environmental conditions needed for species survival and carrying out its life function. A species may have two niches: fundamental niche which occur when species have no completion and realized niche which is found when species have completion from similar species.

Symbiosis is a mutually beneficial interaction between two species. For example, humans have a symbiotic relationship with many bacteria found in our intestine or symbiosis of plant and pollinator. It leads to co-evolution i.e. if evolution happens in one symbiont then it creates selective pressure on other symbiont. (Ref. 5)

Prey-predator relationship is another interaction which generates selective pressure on both prey and predator species. Predators hardly lead to extinction of prey species as predator developed traits (such as running in deer, quill in porcupine, and bad smell in bombardier beetles, thorns and poisonous chemicals in plants) which helps them to avoid predation. Predators also developed traits under selective pressure of obtaining food such as keen eyesight, cryptic coloration etc.

Biogeographical realms and biomes

Based on the divergence of a few ancestral species in various parts of the world to fill different ecological niches available in different parts of the world, we can divide the whole world in different biogeographic realms. Due to differences in originating ancestral species, different taxa (species, families, and orders) filled similar ecological niches in different Wallace realms. Animals or plants filling an ecological niche in a given realm have different genetic makeup than animals or plants found in a similar ecological niche in another realm. For example, the ecological niche which is filled by bison and pronghorn antelope in North America is filled by capybara in South America and by kangaroos in Australia.

The major biogeographic realms based on similarity of genetic makeup of animals (e.g. vertebrates in these provinces are more closely related to each other than animals of other provinces) of Earth are: Nearctic (North America), Neotropical (Central and South America), Palaearctic (Europe, northern Asia, northern Africa), Ethiopian or Afro tropical (Central and South Africa), Oriental (South Asia and Malaysia), Australian, Antarctic and Oceania (Fig. 5).

The biogeographic realms based on similarity of plant taxa are: Boreal floral region, Palaeotropical floral region, Australian floral region, Neotropical floral region, Cape floral region, Antarctic floral region.

Similar environments around the world form similar ecosystems which are collectively termed *biomes*. For example, most of the world's deserts are found around 30^{o} latitude due to similar climatic conditions caused by subsiding air masses. Similar environments provide similar opportunities for life to evolve. This is the reason, in biomes we found functionally and morphologically similar species (a process called convergent evolution), but not necessarily similar in their genetic heritage and internal makeup. This is known as the *rule of climatic similarity*.

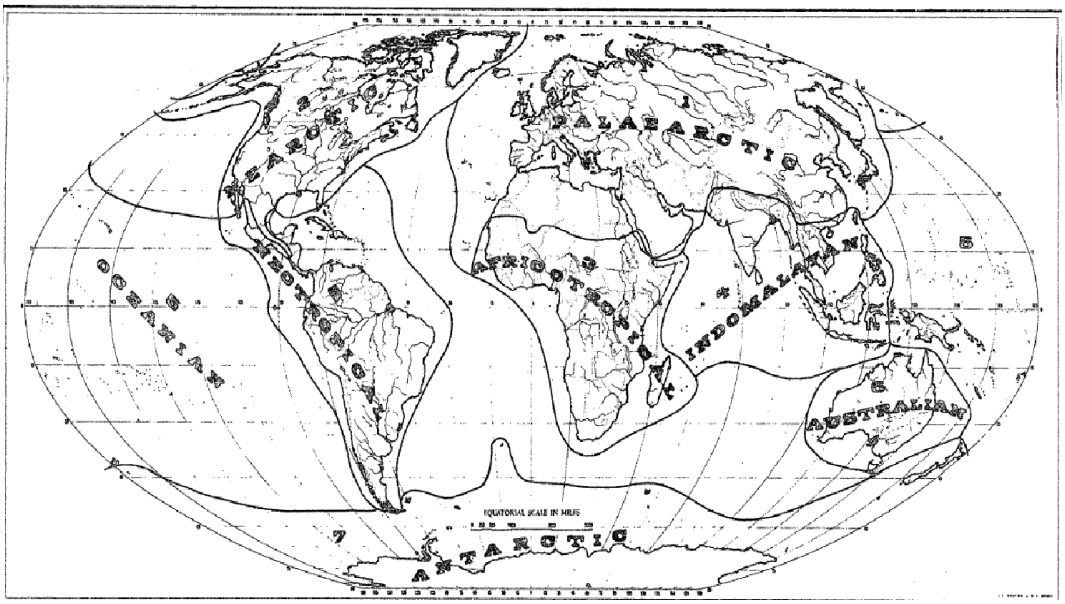

Figure5. Biogeographic realms of the world for animals (Source: Ref. 6)

We can understand convergent evolution by example of plants which are found in deserts of North America and East Africa (Fig. 6). Joshua tree and saguaro cactus of North America and Euphorbia of East Africa are similar in morphology, shape and function. All have succulent stems which have replaced leaves as sites of photosynthesis, and have spiny projection. However, these plants are not closely related. Joshua tree belongs to family agave, the saguaro is a member of the cactus family, and Euphorbia is a member of the spurge family. The convergent evolution of around 180 million years resulted in conversion of three quite different ancestor species to morphologically and functionally similar species.

(A) (B) (C)

Figure6. Convergent evolution: Joshua tree (A) and saguaro cactus (B) of North America are functionally similar to Euphorbia tree (C) of East Africa.

Joshua and Euphorbia trees function similarly and have the same niche, but they both are not closely related. The difference between biome and biogeographic realms is: the realm is based on who is related to whom and biome is based on niche and habitats. Species within a given realm are more closely related to each other than to species of other realms. Same ecological niche in different realms will be filled by species that perform specific functions and may look similar to each other but will have quite different genetic ancestries. So, a realm is actually an evolutionary unit.

The strong relationship between climate and life suggests that if we know the climate of a region then we can predict what type biome could be found in that region, and can make a pretty good suggestion about shape and form of organisms which could be found in that biome including its biomass and productivity.

Divergent evolution (Fig. 4) is another process which affects life's biogeography. Divergent evolution happens when a population is divided and isolated mostly due to creation of geographical barriers. Both divergent and convergent evolution increases Earth's biodiversity.

5.5 Biogeography of India

India is a part of Oriental or Indomalayan realm. The other constituents of this realm are: Southeast Asia and Malaysia-Indonesia. India's biogeography is made up of different biogeographic zones and biotic provinces found in a biogeographic zone. *Biogeographic zones* are defined as large distinctive unit of similar ecology and made of similar type of biomes e.g. The Himalaya, The Western Ghats etc. Biotic province is defined as a secondary unit within a zone where special emphasis is given to particular communities separated by geographical barriers or gradual change of environmental factors. For example, North-West and West Himalaya separated by the Sutlej River forms biotic provinces of the Himalaya biogeographic zone of India. The biogeographic zones of India and associated biotic provinces are mentioned in table 2 and figure 7.

Table 2: Biogeographic zones and biotic provinces of India

S. No.	Biogeographic zone	Biotic province
1.	Trans-Himalaya	Ladakh mountain, Tibetan plateau
2.	Himalaya	North-West, West, Central and East Himalaya
3.	Semi-Arid	Punjab plains, Gujrat-Rajputana
4.	Gangetic plains	Upper and Lower Gangetic plains
5.	Desert	Thar, Kutch
6.	North-East	Brahmaputra valley, Northeast Hills
7.	Deccan Peninsula	Central highlands, Eastern highlands, Central Plateau, Chhota Nagpur, Deccan South
8.	Coast	West and East coast, Lakshadweep
9.	Western Ghats	Malabar plains, Western Ghats
10.	Islands	Andaman and Nicobar

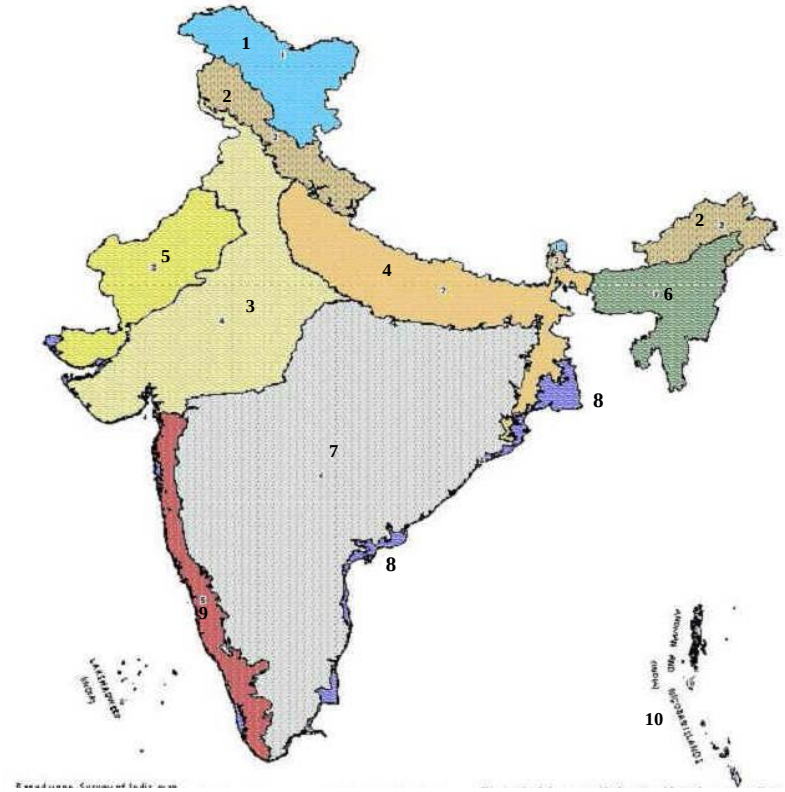

Figure7. Biogeographic zones of India. Legends in figure are the S. No. of Table 2. (Source: Wildlife Institute of India)

The rich variation of topography, climate and geology of land in India created many different habitats and accordingly the biodiversity of India is also very high. Before discussing the biodiversity of India in detail, let us understand about biodiversity patterns and what are global hot spots of biodiversity?

5.6 Biodiversity Patterns

If we talk about global biodiversity patterns then as we move from 0^o latitude (equator) to 90^o latitude (poles) biodiversity generally declines. With very few exceptions, the richest biodiversity is found in tropics (23.5^o N to 23.5^o S) than in temperate and polar regions. The main reason for the decline is the decrease of average temperature as we move from equator to poles. Similar decline in biodiversity is observed as we move to higher altitudes in the mountain range. The variation of biodiversity with latitude is called *latitudinal gradient*. The latitudinal gradient could be understood by following examples.

If we focus on taxa of birds then Columbia which is around 0^o latitude has 1400 bird species, New York at 41^o latitude has 105 species while Greenland located around 71^o latitude has just 56 bird species. India, with much of the land area situated under tropical latitude, possesses more than 1200 bird species. As an another example, we can consider taxa of vascular plants: a forest of Ecuador can possess 10 times more diversity of vascular plants than a forest of the same area in temperate regions like the Midwest of the US.

The tropics are a hotbed of biodiversity which could be understood by having a look at biodiversity of the Amazonian rain forest of South America. The Amazonian rain forest has the greatest biodiversity in the world – the rain forest is home to more than 40,000 species of plants, 3,000 fishes, 1300 birds, 427 mammals, 378 reptiles, 427 amphibians, and more than 1,25,000 species of insects.

Why are tropics hotbeds of biodiversity? There are many hypotheses proposed to explain biodiversity richness of tropics. Three important ones are: (1) Tropical latitudes remained undisturbed during the long evolutionary history of Earth. These latitudes like temperate latitudes have not suffered from frequent glaciations, so the tropical latitudes got long evolutionary time which subsequently increases the speciation. (2) Tropical latitudes almost have no seasonal variation, this provide relatively less disturbed habitat which in turn assisted the evolution of species in all available niches. (3) Tropics receives highest amount of solar energy which results

high productivity, the higher productivity of tropics than other biomes might indirectly led to higher speciation.

At a local level following factors tend to increase diversity.

(1) A physically diverse habitat which provided more niches. A meandering river has more species than a channelized river.

(2) Moderate amount of disturbance in the ecosystem such as fire in patches in big forests or seasonal flooding in wetlands.

(3) Almost constant or small variation of environmental conditions (temperature, precipitation, nutrients etc.). This explains higher diversity in tropics than in temperate regions.

(4) Increase of diversity at one trophic level increases diversity at other trophic level such as high diversity of plants supports high diversity of insects and birds since increase of habitat for these consumer species.

(5) An environment highly modified by life such as a soil rich in humus (organic matter) supports more diversity.

Hotspots of biodiversity

We are losing the rich biodiversity of Earth at an unprecedented rate. The major cause of this is human developmental activities. Most biodiversity rich regions are in developing tropical regions which have poor financial resources to conserve their rich biodiversity. To resolve the dilemma few regions of the world are recognized as biodiversity hotspots. The regions are given priority in conservation efforts since these occupy only 2.4% of Earth's land surface, but they are home of more than 50% world's endemic plant species (vide supra) and support 43% of endemic birds, mammals, reptiles and amphibians of Earth.

The criteria for regions to be recognized as biodiversity hotspot are: (1) they should support at least 1500 vascular plants as endemic (restricted to a given region) i.e. they should have high plant diversity which could not be found anywhere in world, or simply they should be irreplaceable. (2) Facing threat of habitat destruction which is recognized by 30% or less vegetation left in the region from its original undisturbed state. (Ref. 7) As per above criteria, 36 regions of the world are recognized as biodiversity hotspots (Fig. 8 and Fig. 9).

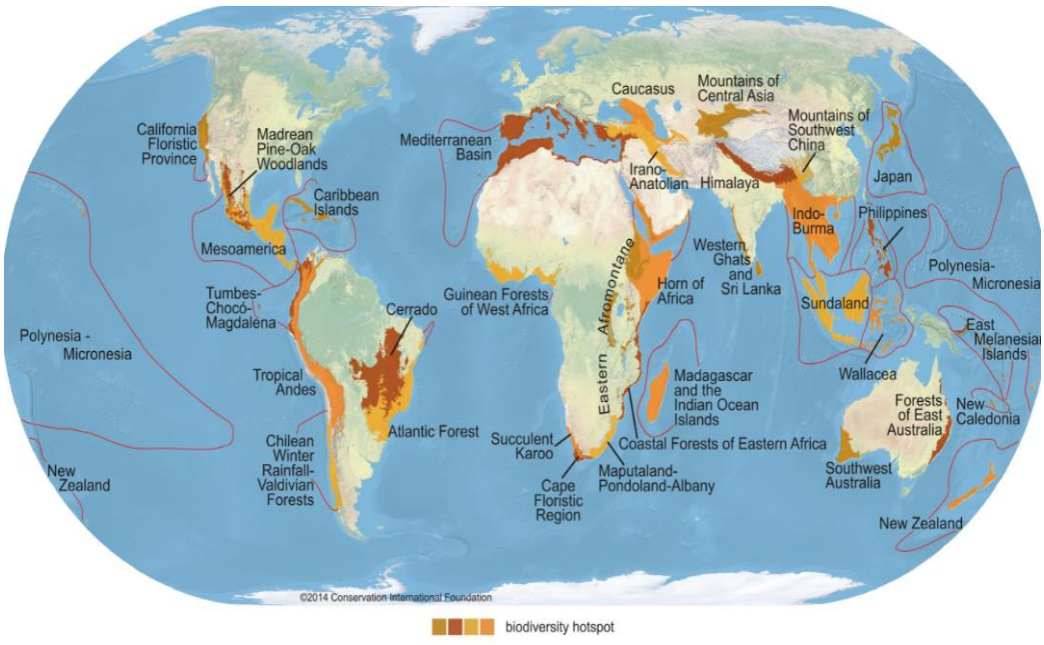

Figure8. The geographical distribution of biodiversity hotspots of the world

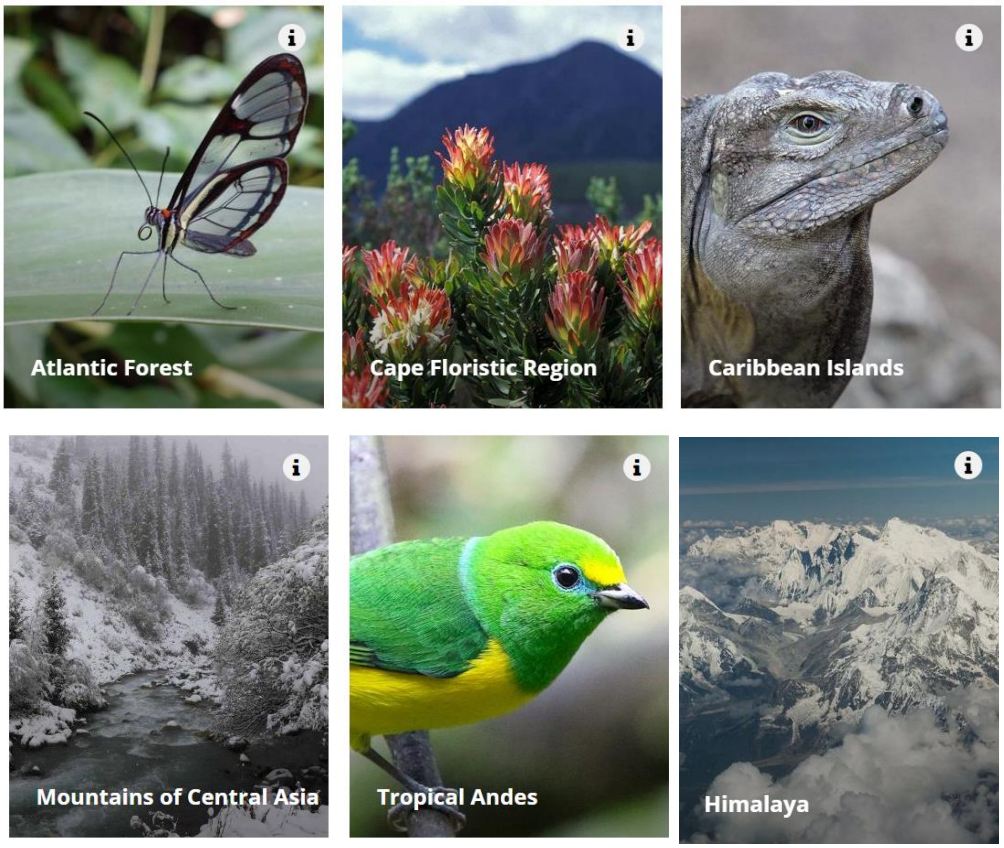

Figure9. Few biodiversity hotspots of the world (Source: Conservation International)

Countries which have a relatively high proportion of biodiversity are called *mega diversity nations*. India which possesses four biodiversity hotspots is a mega diversity nation. Countries with higher biodiversity than India are located in South America (e.g. Brazil) and South-East Asia (e.g. Malaysia, Indonesia). Let's understand more about India's biodiversity hotspots.

5.7 Biodiversity Hotspots of India

Western Ghats

As also mentioned in the previous unit Western Ghats are made of mountain range running parallel to the West Coast of India. The mountain range creates a rain shadow and high rain zone which supports evergreen forest and grassland (Shola grassland) including dry and moist deciduous forest ecosystems. Due to this combination Western Ghats are home to 30% of all species found in India despite covering 6% land area.

The part of high biodiversity is rich assemblage endemic species of plants, reptiles and amphibians.

Plants: Of 4000 plant species found in Western Ghats and nearly 1500 are endemic. The Nilgiri Mountains are richest in endemism of flowering plants with 82% of plant species restricted to this region.

Amphibian: Western Ghats is home to approximately 126 species of amphibian from 24 genera. With 82% endemic species of amphibians, Western Ghats has the highest endemicity of amphibians in India. A whole new family of frogs was discovered in Western Ghats. Malabar torrent toad is one of the prominent endemic amphibians of the hotspot.

Reptiles: Western Ghats supports approximately 157 species of reptile of which 50% are endemic to the region. Most of these species are found in evergreen forest. About 70% of Uropeltidae snakes are endemic to Western Ghats.

Birds: Sixteen species of birds are endemic to Western Ghats. These are mostly found in southern Western Ghats and Shola grassland.

Mammals: Two flagship mammals, the endangered Asian elephant and the endangered tiger are part of Western Ghats. Little is known about small carnivores and rodents.

The cause of highest endemism of Western Ghats is their isolation from other moist areas.

Himalaya

Himalaya, the highest and geologically youngest mountain chain of the world, stretches from northern Pakistan to northwestern states of India to Nepal to Bhutan to northeastern states of India bordering Myanmar and China, in the form of arc (Fig. 10). Himalaya is a transition zone between Pale arctic and Indo-Malayan realms. Both realms contributed towards species diversity of Himalaya. Due to rugged and inaccessible terrain the biodiversity of Himalaya is underestimated in most of the texa.

Plants: Around 10,000 species of plants are recorded in Himalaya hotspot, of these 3160 species of 71 genera are endemic in various parts of Himalaya. Extremely rich diversity of orchids is found in eastern Himalaya. Even at an elevation of 5500- 6000 m which are permanently covered with ice; we can find record diversity of vascular plants.

Birds: Of 980 birds found in Himalaya only 15 are endemic. The prominent birds of Himalaya include: endangered white winged duck, critically endangered white-bellied heron, and critically endangered Bengal florican.

Mammals: Himalaya is home of 300 species of mammals of which around 12 are endemic to Himalaya like Endangered golden languor, critically endangered pygmy hog which is mostly found in Assam state of India. The alluvial grassland supports some of the highest density of tigers in the world.

Indo-Burma

As shown in figure 10, Indo-Burma hotspot is part of tropical Asia. The Himalaya and Indo-Burma hotspots overlap in the North-East region of India. Indo-Burma hotspot is situated east of Ganges-Brahmaputra lowland and extends to Myanmar, Thailand, Laos, Vietnam, Cambodia and parts of south China (Fig. 10). The territory of Indo-Burma comprises the whole range of Anna mite Mountains including eastern extension of Himalaya. It also includes isolated plateau, extensive areas of limestone karst and floodplain and delta regions such as Great Lake of Tonle Sap, Southeast Asia's largest and most productive lake in Cambodia.

Due to high variation of landforms and climate, Indo-Burma hotspot occupies the top ten positions in richness of biodiversity. The reason for high biodiversity of hotspots is diverse topography, tropical climate and evolutionary history dominated by fluctuating Pleistocene sea level which combined and isolated ecosystems and resulted in high speciation. Still we are discovering new species in this hotspot of biodiversity which is evident in the discovery of six large mammal species since 1992 like the discovery of critically endangered saola in the Anna mite Mountains of Vietnam. Other important species are the critically endangered Sunda pangolin of Cambodia and critically endangered Delacour's languor of northern Vietnam.

Lowland evergreen forests of hotspot are more species rich forest possessing many endemic animals and plants. Of the total 1300 threatened species of plants, 600 are part of the Indo-Burma hotspot alone. The Highlands of Southeast Asia shows rich diversity of flora due to complex merging of flora from India, China and Malaysia.

Figure10. Himalaya and Indo-Burma hotspots of biodiversity (Source: Critical Ecosystem Partnership Fund)

Swamps, which are mostly found around Lake Tonle Sap, support many endangered large water birds. The most enigmatic bird species is white-eyed river martin found in the wetlands of Thailand. The biodiversity of the ecosystems of limestone karst formation which is widely

distributed in the hotspot is largely unexplored. The hotspot also supports a wide diversity of freshwater turtles.

Sundaland

Sundaland hotspot comprised Malaysia, western half of Indonesian archipelago, Singapore, Brunei, and Nicobar Island of India (Fig. 11).

Figure11. Sundaland is a biodiversity hotspot.

The topography of Sundaland comprises volcano, swamp, mountain range, plains and coastal waters. It comprises 17,000 islands of Indonesia and is dominated by two islands of Borneo and Sumatra. The diverse topography and association and separation of these islands during Pleistocene sea level resulted in rich biodiversity with high endemism. It supports 25,000 species of vascular plants of which 60% are endemic. The hotspot is home to 380 species of mammals. Most prominent mammals of hotspot are: critically endangered Borne an orangutan and critically endangered Sumatran orangutan.

The Andaman and Nicobar groups of islands are separated from each other by the 160 km wide Ten Degree Channel of sea. The Andaman group is at north and Nicobar group is at south of Ten Degree Channel.

5.8 India as Mega Diversity Nation

Geological history of the landmass of India explains the rich biodiversity of India. A geological event some 200 million years ago split the giant Pangaea in two continents: Northern Eurasia and Southern Gondwana which include India, Australia, Africa and Antarctica. Some 140 million years ago Indian subcontinent was a large island situated at 50°S latitude. (Ref. 8) After that it started its northward journey towards Asiatic plate from which was separated by the Tethys Sea. India collided with Asia some 40-50 million years ago causing the rapid uplift which resulted in the closing down of Tethys Sea and creation of Himalaya. But, before the rise of the Himalaya, plants and animals that have evolved in Europe and the Far East migrated to Indian subcontinent. Finally, Ethiopian species which were adapted to African Savannah and semi-arid regions migrated to India. The special geographical position of India between three centers of evolution and its later isolation by oceans and Himalayan range, coupled with adaptive radiation, made India a mega diversity nation.

India is among top 10-15 nations which are endowed with rich biodiversity of plants and animal life. In addition, many plants and animals are only found in India, not elsewhere in the world. Around 18% of plants found in India are endemic to the country. The flowering plants occupy one third of the diversity of endemic plants found in India. Among amphibians 62% are unique to India. Of 153 species of lizards 50% are endemic to India. High endemism is also reported in other taxa such as insects, marine worms, centipedes, mayflies and freshwater sponges.

The overall position of India in the world, in terms of diversity of various taxa is given in table 3.

Table3. Biodiversity of India

Taxonomic category	India's World Ranking	Number of species in India
Mammals	8th	350
Birds	8th	1200
Reptiles	5th	453
Amphibia	15th	182
Angiosperms	15th-20th	14,500

India not just possesses high diversity of wild animals and plants, but is also rich in natural diversity of cultivated crops and breed of domestic animals. The traditional Indian variety of cultivars includes around 50,000 varieties of rice, and a number of cereals, vegetables and fruits. Western Ghats, Easter Ghats, Himalaya, and North-Eastern hills are the places where we find the highest diversity of traditional cultivars.

The Indian gene banks have collected over 34,000 cereals and 22,000 pulses grown in India. There are 27 indigenous breeds of cattle, 40 breeds of sheep, and 27 and 8 breeds of goats and buffaloes, respectively. The more about the value of biodiversity would be discussed in the next unit.

5.9 Endangered and Endemic Species of India

Endangered species

All species need a group of individuals (a pack of wolf, flock of birds etc.) for survival and reproduction. A critical number could be estimated for each species, below which the population of species cannot recover. A species whose population is declining fast is called *threatened species* and species whose population is at or near its critical number is called *endangered species*. To maintain Earth's biological wealth, the International Union for Conservation of Nature keeps track record of all threatened and endangered life forms and maintains a list of these species called Red List or IUCN Red List. According to recent IUCN Red List data 28% of all recorded species are threatened with extinction.

Few endangered species of India are: Lion-tailed macaque, Royal Bengal tiger, red panda, and Nilgiri tahr (Fig. 12).

(A)

(B)

(C) (D)

Figure12. Some endangered species of India: (A) Lion-tailed macaque, (B) Royal Bengal tiger, (C) Red panda, (D) Nilgiri tahr

Lion-tailed macaque is an endangered species of evergreen forest of Western Ghats. Royal Bengal tiger which is found in many terrestrial habitats such as Terai and Sunderban Delta of India is an endangered species due continuous decline of its population. Red pandas inhabit conifer forests of Himalayan mountain of India and are declining in numbers. Nilgiri tahr inhabits Shola grassland of Western Ghats and is an endangered species.

Endemic Species

Plants, animals and other species which have evolved in an isolated habitat and are adapted only to environmental factors present in the unique isolated habitat are called endemic species.

Endemic plants of India

Some of the examples of endemic plants of India, listed in both IUCN and Botanical Survey of India databases, are: Fairrie's Paphiopedilum (*Paphiopedilum fairrieanum*), *Pimpinella tirupatiensis*, Himalayan Cypripedium, *Nepenthes khasiana* (Fig. 13). (Ref. 9)

Fairrie's Paphiopedilum is an orchid endemic to Eastern Himalaya especially Sikkim of India. It inhabits forest, shrubland and grassland of Eastern Himalaya and is critically endangered. The flowering plant *Pimpinella tirupatiensis* is endemic to Tirupati hills of Chittoor district of India. It inhabits mostly rock peaks and cliffs. Himalayan Cypripedium or Himalayan slipper orchid is in the amazing species category and endemic to Himalayan hotspots. The specific habitat requirement makes the species very sensitive to environmental changes and now this Himalayan orchid is a rare species. The carnivorous plant (pitcher plant) *Nepenthes khasiana* is endemic to Khasi hills of Meghalaya. Of all species of genus *Nepenthes* only *Nepenthes khasiana* is found in India. It is found in dense humid forest of high altitude. It uses its pitcher to trap insects for compensating nitrogen deficiency in soil.

(A) (B)

(C) (D)

Figure13. Endemic plants of India: (A) Fairrie's Paphiopedilum, (B) *Pimpinella tirupatiensis*, (C) *Nepenthes khasiana*, (D) Himalayan Cypripedium.

Endemic animals of India

We have already discussed many endemic animals of our country during discussion of biodiversity hotspots. Few more endemic animals of India are: Hangul, Indian wild ass, golden languor, and pygmy hog (Fig. 14).

(A)

(B)

(C)

(D)

Figure14. Few endemic animals of India: (A) Hangul, (B) Indian wild ass, (C) Golden languor, (D) Pygmy hog.

Hangul is a deer species which is endemic to Jammu & Kashmir region of India especially around Dachigam National Park. Due to illegal hunting the hangul are critically endangered now. Indian wild ass or ghudkhar is endemic to the desert of Little Rann of Kutch of India. Its population is currently declining. Golden languor or Gee's golden languor inhabit forest belt confined by Manas River in East and Sankosh River in West in Assam state of India. The forest habitat is further confined by Brahmaputra River in south and foothill of Black Mountain in Bhutan. Due to fragmentation of habitat the golden languor are now endangered. Pygmy hogs are endemic to Terai grassland of India, however now their distributional range is from northern West Bengal to northwestern Assam, in and around Manas National Park of India. Pygmy hogs are endangered now due to habitat loss caused by human activities and flood control schemes in Assam which are converting grassland to different ecosystems due to ecological succession.

Summary

The biological wealth of Earth exists at three important levels of organization: genetic, species and ecosystem. We recognize and name enormous species biodiversity by organizing in decreasing order of similarity starting from a species to genus and finally to the highest level; the kingdom of species. There are five kingdoms of species: Monera, Protista, Fungi, Plantae, and Animalia. We have already recorded about 1.5 million species which exist on Earth, but most logical estimates put the species biodiversity at 8.7 million. Why are there so many species on Earth? It could be explained through the process of genetic mutations and natural selection. Continent drift caused by plate tectonics created new climate and environmental factors through isolation and combination of landmasses, generation of mountain ranges and modifying general atmosphere and ocean circulation. The changing environmental factors acted as selective pressure on species, which combined with the process of genetic mutations and gene flow resulted in varied adaptations in isolated populations of ancestral species. The millions of years of continuous evolution in an isolated population become so enormous they cannot interbreed if somehow they recombine again

or we can say formation of a new species occurred from the original species. The phenomenon is also called speciation. The heterogeneity of habitat created by plate tectonics and biotic pressure generated by interactions between populations of species created adaptive radiation of ancestral species. The process of evolution and plate tectonics divided our Earth in biomes and biogeographic realms. The biomes are similar ecosystems at different continents characterized by similar climates. The similar climate provided similar ecological niches, but since various continents separated at different points of time the similar ecological niches are filled by ancestral species which are quite different in genetic makeup and resulted in convergent evolution where species were quite different genetically but similar in shape and functions. Biological realms are generated from divergent evolution where the same ancestral species filled different ecological niches available in isolated geographical regions. Biogeography of India is made of ten Biogeographical zones which are large distinctive land areas of similar ecology. Each biogeographic zone of India is further divided into biotic provinces which are ecological communities separated by dispersal barriers. The species richness of different areas around the world is not the same, but globally species richness declines as we move from the equator towards the poles of Earth. The tropical regions are a hotbed of biodiversity. The variation of species richness is also found at local level. Regions with high variation of topography and almost constant environmental conditions support more biodiversity than regions with extreme amounts of disturbance and having stressful conditions like Alpine tundra, Deep Ocean and desert. Based on the richness of biodiversity and endemism we have identified 36 regions of the world as hotspots of biodiversity. The four of these hotspots are part of India which makes India a mega diversity nation. Indian subcontinent originated from collision Indian plate to Asian plate which is responsible for creation of Himalaya, but before rise of Himalaya a many species from evolved in Europe and Far East migrated to Indian subcontinent and got isolated, which make India a country with very good endemicity. Many of the plants and animals found in Himalaya, Western Ghats, Andaman and Nicobar Islands and Northeastern states (part of Indo-Burma hotspot) are endemic to India. Recently, we are suffering from loss of biodiversity and many of Indian species like tiger, red panda, and Nilgiri tahr including many endemic species have become endangered now.

Keywords

Biodiversity, Genetic diversity, Species diversity, Ecosystem diversity, Biological name, Taxa, Natural selection, Genetic mutation, Genetic drift, Continental Drift, Tropics, Biotic factors, Biogeographical realms, Biomes, Convergent evolution, Divergent evolution, Speciation, Biogeography of India, Hotspots of biodiversity, Himalaya, Western Ghats, Indo-Burma, Sundaland, Nicobar Island, Endemic species, Endangered species, IUCN Red List

Self Assessment

1. Occurrence of different genetic variants of a species in a region is called its_____

A. Species diversity
B. Ecosystem diversity
C. Genetic diversity
D. Cultural diversity

2. Which of the following countries is richest in ecosystem diversity?

A. Saudi Arabia
B. Norway
C. India
D. Nepal

3. Which of the following ecosystems exist in India?

A. Tropical forest
B. Coral reef
C. Hot desert
D. All of the above

4. Number of different types of plants and animals which exist in a country is called its_____

A. Species diversity
B. Ecosystem diversity
C. Genetic diversity
D. Cultural diversity

5. There exist_____ kingdom of species on our Earth.

A. 5
B. 1
C. 2
D. 3

6. The first organization which is made of similar type of species is known as_____

A. Class
B. Phylum
C. Kingdom
D. Genus

7. The biological name of human is_____

A. Homo erectus
B. Hominids
C. Homo neanderthalensis
D. Homo sapiens

8. The first word of biological name of a species tells its_____

A. Kingdom
B. Family
C. Phylum
D. Genus

9. Of all species which exist on Earth _____% are animals.

A. 70
B. 100
C. 10
D. 20

10. Angiosperm is a division of_____

A. Flowering plants
B. Animals
C. Non flowering plants
D. Fungi

11. As we moves from equator to higher latitude richness biodiversity _____

A. Increases
B. Decreases
C. Remains constant
D. All of the above

12. One of the reasons that tropical latitudes (tropics) are hot of biodiversity is_____

A. High primary productivity

B. Frequent glaciations
C. Less variation average temperature
D. Both high primary productivity and less variation of average temperature

13. A region is declared a hotspot of biodiversity if it is _____

A. Associated with significant biodiversity
B. Under threat from humans
C. Associated with high endemism
D. Associated with high biodiversity, high endemism and threat from humans

14. Indo-Burma hot spots covers_____

A. North Eastern states of India
B. Indo-Chinese sub region
C. Gangetic plains
D. Andaman & Nicobar Islands

15. _____ is part of Eastern Himalayan hotspot.

A. Sikkim
B. Mizoram
C. Bangladesh
D. Jammu and Kashmir

16. Species which are on the verge of extinction are known as_____ species.

A. Endangered
B. EDGE
C. Endemic
D. Extinct

17. Lion tailed macaque is an endangered species which is found in _____ region of India.

A. Sunderbans
B. Western Ghats
C. Himalaya
D. Eastern Coast

Answer for Self Assessment

1.	C	2.	C	3.	D	4.	A	5.	A
6.	D	7.	D	8.	D	9.	A	10.	A
11.	B	12.	D	13.	D	14.	B	15.	A
16.	A	17.	B						

Review Questions

1. What is biodiversity? Explain its various types.
2. How do we classify Earth's enormous biodiversity and we name a species?
3. Explain the roles of genetic mutation and natural selection in the evolution of species.
4. What is continental drift? How does it contribute to the increase of biodiversity on Earth?
5. What are biological realms and biomes?
6. Explain convergent and divergent evolution with one example each.
7. How does biodiversity vary at global and local level?

8. Explain biogeography of India.
9. What are hotspots of biodiversity?
10. Name hotspots of biodiversity which are part of India.
11. Why are the Himalaya and Indo-Burma hotspots of biodiversity?
12. Why India is called a mega diversity nation? Explain.
13. Write a note on some endemic species of India.
14. Name the countries which are part of Sunderland hotspot of biodiversity. Which Indian region is part of Sunderland hotspot?

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Unit 06: Threats to biodiversity

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Summary

Key words

Self assessment

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Objectives

After completion of this chapter you will be able to

- know consumptive and productive use of biodiversity.
- understand the social, ethical, aesthetic and information value of biodiversity.
- understand the ecological value of biodiversity in generating ecosystem services.
- understand the causes of loss of biodiversity.
- know what is in-situ conservation.
- know national parks and wildlife sanctuaries of India.
- understand the ex-situ conservation method.

6.1 Introduction

We have learned about the rich biodiversity of Earth in the previous unit. Ironically, we are also suffering from loss of biodiversity at an unprecedented rate which is at least 100 higher than the background extinction rate. The major cause of the loss is: human developmental activities. In the present unit we shall discuss what the values of biodiversity are and how humans are also a part of the complex web of life which evolved on Earth over billions of years. Without biodiversity we do not have air to breath, water to drink and food to eat. By conserving and increasing the abundance of biodiversity we can also solve many of our current problems (climate change, poverty, health etc.). What are the causes leading to this huge rate of loss of biodiversity and how we can save our rich biodiversity, are the topics that are discussed next after learning the value of biodiversity.

6.2 Value of biodiversity (Biodiversity services)

After learning about the enormous biodiversity of our Earth, the question is what the value of biodiversity is for us. All of our renewable natural resources (food, freshwater, industrial raw materials, substantial amounts of energy, breathable air etc.) are obtained from ecosystems found in a nation. The ecosystem is made of a community of species which interact with each other and with abiotic components and makes the ecosystem functioning. The functioning ecosystem generates all renewable resources on which our life and economy depends. The biodiversity of a nation and ecosystems they create is called the biological wealth of a nation. To get the maximum sustainable output of resources from the ecosystem it is essential all its biodiversity (the richness and abundance of species) should remain intact.

The importance of biodiversity or particular species in the functioning of the ecosystem is called its ecological value. There are also many other values which are associated with biodiversity. These are consumptive use value, productive use value, ethical and social value, aesthetic value, and information value (Fig. 1). Above values of biodiversity can be classified in two major categories: (1) Instrumental or utilitarian value, (2) Intrinsic value or value at their own sake. Any clear benefit of a species to humans is called its instrumental value, however even if we are unable to find any direct or clear benefit of any plant, animal or microbe to humans, still it has the right to exist and thrive on Earth since they have intrinsic value. The consumptive and productive use values, aesthetic, and information value can be placed under the category of instrumental value and ecological, ethical and social value of biodiversity can be placed under the category of intrinsic value. Let us understand these values in detail.

6.3 Consumptive use value

The direct use of products obtained from living species (like food, fodder, fuel wood, timber etc.) for subsistence by rural and forest dwelling communities is called consumptive use of biodiversity.

Forest dwellers mostly fulfill all their basic needs from biodiversity available in forest. They know the use of various woods and other plant materials obtained from different trees and shrubs for construction and making tools. Fruits, spices, resins, medicinal plants are also used by rural and forest dwellers available in nearby forest. Similarly, fisher folk also use different fishes, aquatic plants and know where to find and how to catch fishes. Hence, these people are more dependent and aware of the importance of biodiversity.

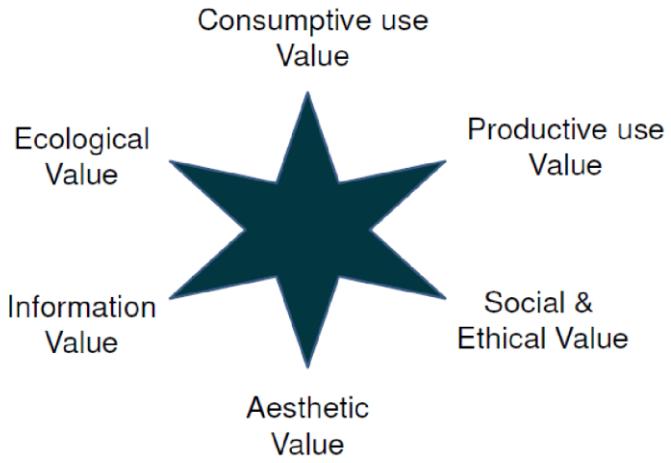

Figure 1. Value of biodiversity.

6.4 Productive use value

The trading of products obtained from living species is called productive use of biodiversity. We are dependent on biodiversity for food, industrial raw materials, medicines and health improving products.

Source for food

There are 7000 plant species which have been used as food by humans, but currently only about 30 species are providing most of our food. The three species – wheat, corn and rice – fulfill approximately 50% of global food demand. So, we may think only a few plants are useful for us out of the hundreds of thousands found on Earth and there is no financial incentive involved in conserving all plants. However, we should be clear in mind that most of our current agricultural plants are developed for maximum yield under optimum pressure. These agricultural plants termed cultivars (*culti*vated *var*iety) are selected for maximum yields and have minimum genetic variability. Cultivars lost all traits which make them resilient to tolerate adverse weather such as drought, frost, untimely rain etc. Due to low genetic variability these cultivars have no ability to adapt to any other biotic or abiotic condition. In contrast, wild relatives of crop plants are naturally selected to survive in different climatic conditions and also have traits to tolerate adverse weather conditions. Their high genetic variability also makes them adapt to changing biotic conditions imposed by outbreak by plant pathogen or abiotic conditions forced by changing climate.

Wild genes. The genes which make wild crop plants tolerant for climatic and parasitic attack could be used to create new cultivars (through plant breeding or modern biotechnology), tolerant for changing climatic conditions, or tolerant to particular disease outbreaks. For example, in the 1970s US maize harvest was saved from blight by incorporating genes from wild strains of maize. Similarly, the rich diversity of wild plants could be used for developing cultivars which are resistant to pest attack. The loss of wild species would eliminate our ability to continuously improve our food plants.

New food plants. Our current crop varieties are able to provide maximum yield only under optimized conditions. These varieties cannot provide sufficient sustainable yield in regions which do not support optimum conditions. For example, to grow high yielding staple food plants in arid regions we need irrigation. Intensive irrigation through canal systems is associated with desertification and is expensive to implement. However, there are wild plants like the wild species of bean family that grow abundantly under dry conditions.

It is estimated that about 30,000 plant species with edible parts could be incorporated in our agriculture system. Many of these could provide good yield in different environmental conditions. For example, every part of a bean plant (winged bean) native to New Guinea is edible: pods, flower, leaves, stem, and roots. The recent introduction of this legume in developing countries significantly contributed to improving nutrition. So, these new plants which exist in the vast plant diversity of our Earth could solve our current problem of freshwater scarcity, land degradation and future problems associated with changing climate.

Source of raw material

Nature has provided us many species for animal husbandry, aquaculture and forestry, so arguments discussed above for food plants could also be applicable for these enterprises. Around 3 billion people in the world depend on wood for cooking and heating. Wood is also an important raw material for paper and pulp industries, furniture and construction industries. Forestry is an enterprise whose main goal is to produce different types of wood in sufficient amounts. The minor products which we obtain from forests are: rubber, oils, nuts, fruits, spices and gums. For some tropical forests the value of minor forest products (MFP) is much higher than timber obtained from them.

We are also developing new processes for use of previously unused components of wood and other biomass to generate monomers and feed chemicals for textile and fast moving consumer goods (FMCG) industries which are currently dominated by petrochemical industries. For example, recent development of catalytic processes for conversion of hardwood to phenol, ethylene, bioresin and bioethanol, have provided chemical feedstock to the fiber, plastic and paint industry and biofuel for the energy industry.[1]

Different wild grasses and weeds are now finding new application for being a new source for particular industrial feedstock, as a given feed chemical (monomers, bioresin, bioethanol etc.) can

obtain much better yield from a particular plant species. Bio-refinery would replace crude oil based traditional refineries in future.

Source of medicine

Natural products or secondary metabolites of plants and other organisms (microbes, marine animals etc.) are used as drugs in the form of botanical mixture of two or more natural products or as single natural products in both traditional and modern medicine. Humans have discovered many promising cures for many deadly ailments by exploring rich biodiversity surrounding them. This exploration is continuing from ancient times to the current modern era. Indian traditional medicine system Ayurveda and Chinese Materia Medica is full of information of many medicinal plants and living organisms useful in reducing human suffering from different ailments.

It is not a traditional system which relies on rich biodiversity, but secondary metabolites of living organisms are still providing new medicine or inspiring the development of new synthetic drugs for emerging diseases such as cancer, HIV, metabolic disorders and diseases caused by drug resistant pathogens. For example, rosy periwinkle is used by indigenous people of Madagascar, in their folk medicine. The plant is endemic to the island (Madagascar), and if it went extinct before 1960 then nobody outside the island knows its medicinal properties. In the 1960s, two natural products vinblastine and vincristine were isolated from the plant which revolutionized treatment of two fatal cancers: childhood leukemia and Hodgkin disease. Before the discovery of these compounds, leukemia was always fatal to children. The use of vincristine in chemotherapy of leukemia provides remission (disappearance of symptoms) in 99% cases.

The story of rosy periwinkle is only one of hundreds of discoveries of promising cures through exploration of miraculous biodiversity of Earth, especially plants and microbes. Few other examples similar discoveries are: (1) Shikimic acid isolated from Chinese tree star anise (name given due to its star shaped fruit) is used in making Tamiflu®, an effective treatment against influenza viruses. (2) Taxol® isolated from Pacific yew (genus: *Taxus*) which is now a most prescribed drug used in chemotherapy of ovarian, breast and other cancers. Table 1 provides examples of a few more drugs derived from different plant sources.

Current progress in analytical and isolation techniques has made it easy to isolate and screen plants' secondary metabolites for activity against various diseases. The exploration biodiversity of intact natural ecosystems (forest, marine etc.) for useful medicinal and health improving compounds and wild genes (the process is called *biological prospecting*) could be improved by conserving both the natural ecosystem with their indigenous peoples. The precious knowledge of indigenous people could be utilized in expediting identification of useful species for human welfare.

Table 1: Popular drugs derived from plant sources.

Drug	Plant Source	Use
Penicillin	Penicillium Fungi	General antibiotic
Quinine	Yellow Cinochona	Anitmalarial
Reserpine	Indian Snakeroot	Reduces high blood pressure
Scopolamine	Thorn Apple	Sedative
Digitoxin	Common foxglove	Cardiac stimulant used in heart diseases

6.5 Social and ethical value

Traditional societies give more value to biodiversity as their life sustaining resource. Their rituals and customs (like reverence given to Mahua trees by Gond tribes or to Banyan and Peepal trees in

Hindu society) are linked with protection of biodiversity. In many tribal communities of India, the whole forest tract is considered sacred and no loping and falling of trees are allowed in sacred groves. The social customs which link a local community with its surrounding biodiversity are known as *social values* of biodiversity.

It is not just utilitarian or instrumental values which explain us why to conserve our biodiversity, but there are also *ethical values* which require that a species should not be made extinct by destroying its habitat and niche even if it has no benefit to humans. Planet Earth is not just created for humans only; it is also a home for all other species which co-evolved with humans. Humans are only a part of Earth's great family. Plants and animals have an equal right to live and exist on Earth which is like an inhabited spaceship. There are many cultural and local traditions which are associated with the sanctity of all life-forms. A detailed discussion of these traditions is made in unit 14.

6.6 Aesthetic value

The amazing species of wilderness are also associated with awe and surprise that they create in us. This is called the aesthetic value of biodiversity. This aesthetic value is the basis of the ecotourism industry. Ecotourism which capitalize on undisturbed pristine ecosystems present in a country is a huge source of foreign exchange for developing nations. This value of biodiversity also motivates countries to create more protected areas in their territories.

The natural ecosystem, whether it is Yellow National Park in the US, Kanha National Park in India or Great Barrier Reef of Australia, also improves mental health by enlightening and relieving stress of visiting persons (Fig. 2). Wild safari, bird watching, rafting, and scuba diving are few of the activities associated with ecotourism.

(A)

(B)

(C)

Figure 2. Aesthetic value of biodiversity: (A) Hot water spring of Yellowstone National Park, US, (B) Kanha National Park, India, (C) Great Barrier Reef, Australia.

6.7 Information value

Many amazing species, which are part of Earth's rich biodiversity, provide us clues to discover new devices and technology to improve human well being including solving problems like climate change, energy crisis, environmental pollution, poverty etc. This value of biodiversity is termed their information value. We can understand the information value by discussing a few examples (Fig. 3).

Electric eel

Electric eel is a fish (Fig. 3A) which can stun its prey and predator both by discharging electricity up to about 600V. It creates such a huge voltage through the specific cells called electrocytes, which stack to each other and form an organ which runs along the length of the fish. The presence of an ion channel embedded in the cell membrane of an electrolyte creates an imbalance (using metabolic energy) of positive and negative charges across the cell membrane which generates a potential difference of millivolts (mV) range. The stacking of these electrolytes forms an arrangement where biological cells are connected in series and thus creates a battery.

We are also working to develop a soft battery for wearable devices and for devices used inside our body like pacemakers, prosthetic organs etc. taking inspiration from mechanism of electric current generation by electric eel. Scientists are trying ion selective hydrogel (made from polyacrylamide and water) to create a flexible and biocompatible battery.[2]

(A)

(B)

(C)

(D)

Figure 3. Information value of species: (A) Electric eel, (B) Tool user Hawaiian crow, (C) Rock munching sea urchin, (D) Komodo dragon

Tool user Hawaiian crow

The tool using behavior of Hawaiian crow (critically endangered species, Fig. 3B) was recently recognized. The crow used a tool to extract embedded prey from wood. Further, juvenile crows do not use any help from adults or social input to become proficient tool users. The tool using behavior is genetically fixed in crows. The discovery can help us in understanding the evolution of tools using behavior in primate lineage. This and other similar discoveries show that skills could also be fixed genetically.[3]

Rock munching sea urchin

Sea urchins are mostly sea floor living globular animals, which lot of prickly spine (Fig 3C). In addition, they also have five razor-like self sharpening teeths in their star shaped mouth. Sea urchin used these teeth to chomp on brittle starfish, coral reef and even rock. Material scientist are trying to mimic the self sharpening mechanism of sea urchin teethes to creates cutting and drilling tools which can sharpen themselves.[4]

Komodo dragon

Komodo dragon is the largest extant monitor lizard (Fig. 3D) endemic to Komodo island of Indonesia. It possesses a large number of genes related to sensing of pheromones and kairomones. The ability to sense kairomones (volatile compounds emitted by other species) gives lizards a good ability to ambush and hunt their prey. The saliva of lizards gets introduced in the prey body during its bite, which induces clotting of blood. However, the lizard also has genes which code for proteins which help it in thinning of blood and in this way the lizard survives the deadly bite of another Komodo dragon. These proteins could help us in developing biologicals for cardiovascular diseases.[5]

6.8 Ecological value

All species of an ecosystem are connected with each other through various population-population interactions (predation, parasitism, competition, mutualism, and commensalism). These interactions are essential to maintain dynamics of different populations of all members of the ecosystem including those directly useful to humans. It is found experimentally that richness of biodiversity increases the resilience of the ecosystem and also stabilizes it in terms of productivity and other functions of the ecosystem.

Every species has an ecological value in a healthy undisturbed ecosystem since it takes millions of years to achieve equilibrium between ecological community and local environmental conditions found in an ecosystem. Every species is an ecological service provider and plays an important part in running the ecosystem. The principle of competitive exclusion requires that species depending on the same resources consume the resources available at different time and space. This diversity stabilizes productivity of the ecosystem against natural and man-made disturbances. We can understand relationship between rich biodiversity and stability of ecosystem by a conceptual diagram shown in figure 4.

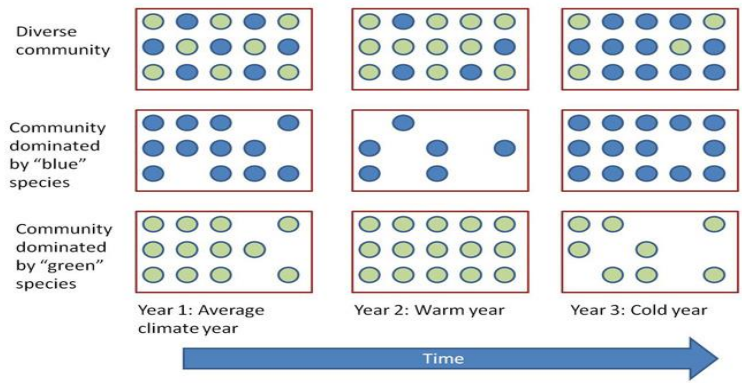

Figure 4. Conceptual diagram explaining relationship between biodiversity and ecosystem stability. (Source: Ref. 6)

Each rectangle in figure 4 shows ecosystem occupied by two plant species represented by green and blue circles. The green circles are plants which thrives (increase in abundance) in warm condition and blue circles are plants which thrive in cold weather. As we can see middle and lower rows of plots show inter-annual variation of productivity (measured by number of plants in plot) while the upper row having diverse communities shows no variation in productivity, since decline of population of one species of plant is compensated by increase of population of other species.

The biodiversity richness also mitigates the outbreak of epidemic and pandemic in a region. When there are many different species requiring the same resources or occupying the same trophic level in an ecosystem, the limited availability of resources (which can support only a limited number of individual species) makes the population of specific species much lower including pathogens and their host. This provides minimum chances of evolution of new parasites (bacteria, virus etc.) from contact of human and wildlife or pathogen host (See case study below).

Case Study: Origin of SARS-CoV-2

Horseshoe bats (Fig. 5) harbor many SARS-related coronaviruses. Bats are the second most diverse group in mammals with 1400 species. During evolution of bats, their 10 genes which mount inflammatory response during infection got disabled. Further, the presence of antiviral genes makes them highly tolerant to viral infection.

Figure 5. Horseshoe bat: Reservoir of SARS-related coronaviruses.

Due to above genetic makeup, bats have more viral infection than any other mammals on Earth and their genome is littered with DNA pieces derived from past viral infections. Bats are generalist species. Encroachment of forests by expanding cropland, urbanization and insensitive animal farming destroyed the niches of specialist species and even made them extinct.

The extinction of specialist species resulted in the rise of generalist species like horseshoe bats. A study based on remote sensing data has also found areas populated by horseshoe bats are also areas with higher forest fragmentation. The insensitive animal farming and wildlife markets (near disturbed forest ecosystems) reduce the immunity of domestic and wild animals in these places, respectively and make them vulnerable to disease outbreaks. The poorly immune domestic and wild animals worked as an intermediate link in transfer of virus from bat to human. The weak immunity of domestic animals and their closeness to bat populations may be one of the probable causes that a newly evolved strain of coronavirus (SARS-CoV-2) jumped from bat to human.[7] So, forest destruction and resultant increases of population of coronavirus harboring bats might have led to emergence of devastating pandemic: COVID-19.

6.9 Ecosystem services

The ecological community of species with its local climate and other abiotic factors creates a functioning ecosystem which provides us many important services on which our life and economy depends. Few important services that we derive not just from a single species but from the whole ecosystem are listed below.

Production of food. Natural ecosystems (grassland, forest, wetland etc.) recharge surface and groundwater reserves essential for sufficient food production through agricultural activities. Natural ecosystem helps in pollination control of pests through pollinator layers – bees, bumblebees, birds, and bats. The wilderness areas also work as banks of wild genes for development of new varieties of crop plants and new breed of domestic animals which can provide maximum yields in a changing climate. Further, food (fishes, wild fruits, species etc.) obtained from the natural system is the part food provisioning service of the ecosystem.

Carbon sequestration and modulation of climate. Forests and especially tropical forests and the ocean work as efficient sinks for excess carbon dioxide released in the atmosphere. A lot of living plant matter is finally converted to humus which contains a lot of carbon, similarly marine algae and shell forming animals settle deep inside the ocean and net carbon (trapped in bodies of marine organisms) got removed from the atmosphere by ecosystems based in oceans.

Big forest attracts more rainfall and moderate average temperature of surrounding area by the process of transpiration and absorbing solar energy. Thus ecosystems protect us from drought, floods and harsh temperatures.

Control of biogeochemical cycle. A healthy ecosystem supports generalist and specialist species which not only dispose of detritus generated in an ecosystem but also enhance nutrients in soil by using atmospheric gases and by releasing trapped nutrients in dead living species back to soil.

Soil retention and formation. This is a very important service performed by the natural ecosystem. The roots of big trees, shrubs and grasses including their leaves protect soil from water and air based erosion. The slow mineralization of humus also helps in generation of soil.

Sandstorm prevention. The rough surface generated by rich vegetation (especially trees) of terrestrial ecosystems reduces velocity of wind and mitigates impact of sand storms in areas near to desert.

Water retention and flood mitigation. As discussed in unit 2, forest protects the watershed of rivers and supplies water in water bodies (river and wetland) throughout the year including mitigating impact of heavy rain.

Provision of habitat for biodiversity. The abiotic factors and biotic community of ecosystems provides niches for all species which are part of the system to survive. In this way, all valuable wildlife self-sustain themselves.

As discussed in case of forest ecosystem (unit 2), the ecosystem services in general can be placed in three major categories: provisioning, cultural and regulative services. In the services discussed above, the production of food is provisioning service while others are regulative services provided by natural ecosystems.

6.10 Valuation of ecosystem services

Biosphere (made from all interacting ecosystems of Earth) is a thin layer of Earth which supports all life forms including humans. However, we are losing our valuable ecosystem mainly due to our developmental activities and rising population. Economic development is essential to provide standard living conditions to all citizens of a nation. But economic development in terms of long term decline of life-supporting ecosystem services may even reduce the welfare of current and future generations. It is essential to access ecosystem services in terms of their monetary value, so the human welfare achieved from particular economic activity or developmental projects and welfare received from the current state of ecosystem services could be compared.

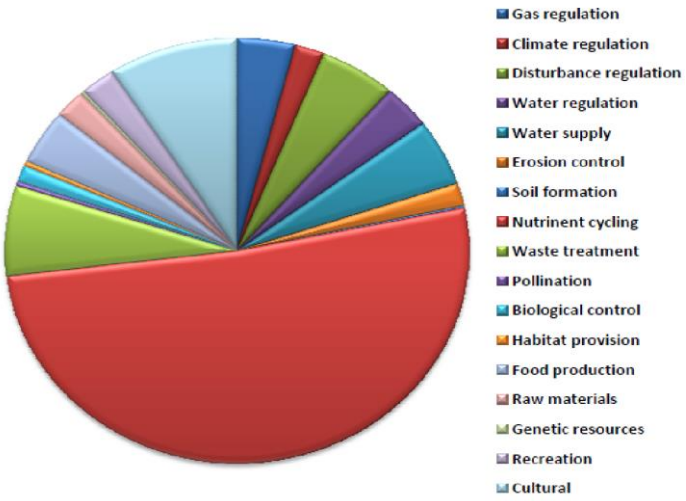

Figure 6. Ecosystem services and their relative contribution. (Source: Ref. 8)

Efforts were made to assign the total cost of ecosystem services provided by the whole biosphere. Mostly, we assign a price tag (monetary value) to ecosystem service by determining cost of human welfare which is lost due to decline of quality and/or quantity of given ecosystem service caused by a developmental project. The valuation of the ecosystem services helps us in conducting environmental impact assessment (EIA) of any major economic activity. Robert Constanza and his colleagues have assigned the price tag for 17 important ecosystem services provided by whole biosphere (Fig. 6). The total average cost of all services comes out to US$ 33 trillion per year around the year 1994. The total gross national product (GNP) of the world at that time was US$ 18 trillion per year. (Ref. 8) Of all the 17 services considered, the biggest contribution was provided by nutrient cycling performed by ecosystems.

6.11 Threats to biodiversity

We have learned about the importance of Earth's vast biodiversity as individual species and as an ecological community of an ecosystem which provides us most of the life-supporting services. Still, we are losing our rich biodiversity at a rate of at least 100 times higher than the background rate of species extinction.[9] This phenomenon is called the sixth mass extinction in geological history of earth which had already experienced five episodes of mass extinctions.

As per 2004 report of IUCN (International Union of Conservation of Nature), in the last 500 years some 784 species got extinct e.g. Dodo, Schomoburgk's deer, Stellar sea cow, three subspecies (Bali, Javan, Caspian) of tiger. In the last 20 years alone, we have lost 27 species. IUCN tracks the status of all species (threatened, endangered, critically endangered etc.) through its red list called IUCN Red List. Currently 37,400 species are facing threat of extinction which is 28% of species accessed till now by IUCN for making IUCN Red List. Not all taxa are facing the same threat of extinction. Amphibians are the most threatened taxa with 41% of species are at verge of extinction. After amphibians, the taxa of sharks and ray, conifers, reef corals, mammals, birds are threatened in decreasing order of vulnerability with 36%, 34%, 33% 26%, and 14%, respectively species under threat of extinction.

The loss of biodiversity is weakening the ecosystems and reducing the quality and quantity of services provided by them. As per the 2008 estimate of TEEB (The Economics of Ecosystem and Biodiversity; a global initiative under UN's Convention on Biological Diversity), the world is losing ecosystem capital at a rate of US$ 2- 4.5 trillion per year. Let us understand the causes of loss of biodiversity.

The four major causes ('The Evil Quartet') which are responsible for current rise in species extinction are: (1) Habitat change, (2) Alien species invasion, (3) Overexploitation, (4) Co-extinction. Recently observed human-wildlife conflict is becoming another cause of decline in the population of wild species.

6.12 Habitat change

Many species are adapted to environmental factors found in their distributional range. When their habitats are changed by conversion or pollution or fragmentation and simplification, then it causes the decline of species population and finally their extinction. Habitat loss is responsible for 36% of all known extinction and is a key factor for currently observed population declines.

Conversion

The wilderness areas harboring many natural ecosystems are converted to agricultural land, range land or taken over by expanding cities for housing, industrial and commercial complexes. When a forest is cleared by cutting trees it is not just the population of trees that declines, but all other species which depend on trees (birds, and other herbivores) also find it hard to survive. For example, loss of forest habitat in Central and South America is the cause of decline of North American songbird population, which uses the Central and South American forest as their winter habitat. The decline of herbivores population leads to decline in carnivores' population.

One of the prime examples of habitat loss is the Amazon rainforest. Initially occupying 14% of Earth's land surface (which gives them title: lungs of planet) these forests are now covering no more than 6% of Earth's land surface. The Amazon rainforest, which is the richest in biodiversity, is being cleared at the fastest rate for soya bean farming or raising beef cattle.

Fragmentation

Wild species are not just threatened by destruction of habitat, but also by fragmentation of habitat. Fragmentations of habitat by roads, railway lines, electric wire etc. interfere with the migration of

species and isolate them in small populations. Isolation of species in a small population reduces their number below the critical value and leads to extinction.

Animals also killed by road accidents while moving from one fragment of habitat to other. More than one millions animals per day are killed by road accidents in US alone. Amphibian occupies the biggest percentage of roadkill. In India, golden langurs which are endemic to Assam are fast declining in population due to rural electrification in villages. Golden langur uses upper canopy of trees for movement and got electrocuted by three phase wire recently installed in villages of Assam.[10] The fragmentation of habitats is also the cause of man-wildlife conflicts especially for animals which need large territory for their survival.

Simplification

Human use of natural ecosystems often simplifies them, such as removal of fallen logs and dead trees from woodland for their use as fuel wood also removes microhabitat of species ranging from woodpeckers to growing saplings of trees. Conversion of natural forests to plantation forest also reduces the population of non-commercial trees and habitat of all other species depending on these trees. Straightening or channelizing a meandering river has similar effects. It destroys many microhabitats and reduces diversity of fishes in a river.

Intrusion

Intrusion of habitats by man-made structures is also the cause of decline of species especially birds. The rise of cell phone and TV towers in rural areas and hilltops, at least interfere with migration of birds. The light used in the towers attract birds at night, birds simply collide with towers and are killed. Somewhere, between 5 and 50 million birds per year die due to the towers. The other cause of killing birds are clear glass windows of high rise buildings, birds don't recognize the barrier and crash on it.

6.13 Alien species invasion

A species which is introduced in a region from different biological realms is called an alien species. These entered in new regions either accidentally or deliberately as pets or for more commercial harvest of marketable items. There are two fates available for such species if they are released from their managed confined habitat: (1) They won't survive in the wild. (2) They may find a new environment much better due to the lack of negative environmental factors in the new environment or they may acquire adaptation to survive in the new environment. In the majority of cases alien species meet the first fate. But, in rare cases they meet the second fate and if this happens then these species become pest or invasive species. In most of the cases invasive species led to decline and in some cases extinction of native species.

Most common example of invasive attack is the accidental introduction of rats in ecologically isolated islands. Rats are responsible for threatening 30% of seabirds to extinction such as decline of the population of boody chick in Chagos Archipelago (group of islands near Mauritius) or by non native rats which eat egg and nestling of the bird. Decline of boody chick also affected the whole coral reef ecosystem as excrement of the chick add nitrogen in coastal water which helps in growth of algae and in turn fish population (Fig. 7).[11]

Figure 7. Boody chick with its nest over coral reef in Chagos Archipelago. (Source: Ref. 11)

Burmese pythons, an endangered species of Indo-Burma hotspot, were imported in the US and sold as pets. The baby pythons which attracted the buyer due to their colorful skin are one of the world's six largest pythons, reaching to length of 7 m and weight 90 kg. When pet baby pythons had grown to full size, these were left in the wild (mostly in south Florida in US) by owners. Now pythons overrun Everglades National Park of Florida and resulted in 99% decline of population of raccoons, 98% population decline of opossum, and 87% decline of population of bobcat, all these species are native of Everglades National Park (Fig. 8). Burmese pythons were also responsible for the disappearance of many native species of rabbits and foxes from the park. Burmese pythons used all above species of the park as their prey.[12] The example explains what happens when we introduce a species native to a different biological realm to another biological realm.

(A) (B) (C)

Figure 8. (A) Burmese python in Everglades National Park, Florida, US (Source: USGS), (B) Nile Perch harvested in Lake Victoria (Source: The Guardian), (C) Seaweed: *Caulerpa taxifolia* (Source: UC, Riverside)

The Nile Perch was introduced in Lake Victoria of east Africa (lake spreads over two countries Tanzania and Uganda of east Africa) around 1954 for increasing production of aquaculture. However, its introduction resulted in near extinction of an ecologically unique assemblage of 200 cichlid fishes native to the lake due to predation and competition for food by Nile Perch. Similar introduction of African catfish *Clarias gariepinus* in India for aquaculture is posing a threat to indigenous catfishes in Indian rivers.

Around 1984, delicate seaweed native to Pacific Ocean near Hawaii and named *Caulerpa taxifolia* was introduced as exotic species to enrich saltwater aquarium exhibits in a zoo of Germany. Due to its beauty the seaweed was introduced in other locations of Germany including the Oceanographic Museum in Monaco. After five years of introduction of *Caulerpa* in Germany, it got accidently leaked in Mediterranean Sea during the washing of the tank of an exhibit aquarium. *Caulerpa*, which is a native of tropical waters and does not grow at temperature below 21^{o}C, *quickly acquired adaptation to survive in chilly water (around 10 ^{o}C) of Mediterranean Sea and also changed its growth patterns*. The *Caulerpa* in Mediterranean Sea grows six times larger than it does in its native habitat of Pacific Ocean.

How *Caulerpa* acquired these traits is not clear. It may have done it through mutation, through hybridization with native seaweeds or it may have dormant genes for required traits. It can grow on all types of substrates like rock, sand, and mud unlike native seaweeds and algae of the sea which do best only on one type of substrate. Its growth rate is so high that it blankets competing seaweeds and causes decline of their population. The invasive strain of *Caulerpa* is also toxic to marine animals such as sea urchin which does not touch it. The seaweed has become an invading monster affecting native algae and animal life of Mediterranean Sea.

6.14 Overexploitation

As we have understood, we are dependent on nature for our food and shelter. When the 'need' turns to 'greed' it leads to overexploitation of natural resources. Overexploitation happens when a species is harvested at a rate higher than their reproduction rate. For example, over-hunting has led to extinction of Steller's sea cow and passenger pigeons. Tiger and many species of rhinoceros are being made endangered due to illegal poaching of these animals for skin (in case of tiger) and rhino for their horn which is used in traditional medicine in Asia and as an ornamental handle of knife in Middle-East. Asiatic elephants are endangered due to their illegal poaching for a task which is a priced material for ivory ornaments. Polar-bear and many reptiles are hunted for their skins which are used in making handbags, rugs, clothes etc.

Illegal poaching flourishes because some consumers have a fad for wildlife products and are willing to pay exorbitant prices for these items. For example, some Indonesian and South American parrots sell for up to US$ 10,000 in the US and a panda-skin rug can easily fetch US$ 25,000. An estimate by Interpol found that illegal wildlife trade is at least US$ 12 billion annually.

Did you Know?

Overexploitation is responsible for 23% of total extinction in the last 500 years.

6.15 Co-extinction

When a species goes extinct the plants, animals and microbes which depend on the species in symbiotic manner also meet the same fate. For example, a species of butterfly in Colorado Mountain got locally extinct in a year characterized by very late snow and freezing. This happened since butterflies lay their eggs in unopened buds of single species of lupine, and hatched caterpillars feed on the flowers. The very late snow and freezing in the year killed all lupine buds, leaving caterpillars without food and causing local extinction. Same fate will be observed for all microbes living in a fish, if the fish went extinct.

6.16 Man-wildlife conflict

Encroachment of habitat of wildlife, poor planning of protected areas for wildlife leads to conflict between human and wildlife and violation of tribal rights leads to man-wildlife conflicts such as man-tiger and man-elephant conflicts. More detailed discussion about these conflicts will be made in unit 11.

6.17 Conservation of biodiversity

In general, the decline of biodiversity makes the ecosystem fragile and reduces the output of services vital for humans. Extinction of keystone species (species important for maintaining biotic structure of the ecosystem) can even lead to collapse of the ecosystem. The conservation of endangered, endemic species could be done in two methods: (1) In-situ conservation, (2) Ex-situ conservation.

6.18 In-situ conservation

The best way of conserving an endangered and endemic species is by making its whole ecosystem a protected area. By making the whole ecosystem containing the habitat of endangered species as protected zone eliminates four major causes (The Evil Quartet) which are responsible for decline of population of endangered species. Initially, to protect endangered keystone species many important projects were implemented in India such as Project Tiger (started in 1973), Project Elephant (started in 1992) etc. and habitat of tiger and elephants declared as protected areas. Currently the focus is on integrated management of protected areas where we want to connect important protected areas with wildlife corridors.

The wilderness areas in our country are protected as per Wildlife Protection Act, 1972. The protected areas (PA) are classified in three major categories in India.

(1) National Park

(2) Wildlife statuary

(3) Biosphere reserve

National park provides greater degree of protection to endangered species as all animals; plants and geomorphic features of the species ecosystem are protected. No human activities are allowed in national parks without permission of the chief wildlife warden.

Wildlife sanctuary as name suggests are areas only permitted to be used by wildlife. Wildlife sanctuaries are made to provide favorable conditions for rare, endangered and endemic species to thrive.

Biosphere reserve is a bigger entity which includes connected national parks and wildlife sanctuaries. There are 104 national parks, 553 wildlife sanctuaries and 18 biosphere reserves in India.[13] The important national parks present in different biogeographic zones of India are mentioned below (Table 2).[14]

Did you Know?

In India, the Island biogeographic zone (composed of Andaman and Nicobar islands) has largest percentage of land under the protected area category.

Table 2. Important National Park situated in different biogeographic zones of India.

S. No.	Biogeographic zone	Protected area (National Park)
1	Himalaya	Valley of Flowers
2	Gangetic plains	Corbett
3	Western Ghats	Periyar
4	Deccan peninsula	Kanha
5	North-East	Kaziranga
6	West Coast	Marine (Gulf of Kutch)
7	Semi-Arid	Gir

6.19 Ex-situ conservation

When a population of an endangered species is near to the critical number needed for survival, then in-situ conservation has little chance for revival of the species. In these cases species are removed from their original habitat conserved ex-situ using methods developed in a new science called *conservation biology*.

These methods are:

(1) Captive breeding in zoological gardens or modern zoos for animal species and botanical gardens for plants.

(2) Gene banks where sperms, ova, seeds or other lives cells of endangered or rare species are preserved by cryopreservation methods for future captive breeding.

(3) DNA technologies like cloning and molecular biology.

The success stories of captive breeding are conservation and revival of all three species of crocodile in India. Guahati zoo of India got success of selective breeding of rare pigmy hog, while Delhi zoo got success in captive breeding of Manipuri brow antlered deer. Captive breeding should be done carefully to avoid in-breeding which may not provide viable offspring.

Cloning is a complex technique in which DNA of endangered species is inserted in egg cells of similar species whose nucleus is removed. The technique still is not so reliable, but with scientific advances we may be successful to create better progeny of extinct species if we have their preserved DNA. Molecular biology techniques could be used for transfer genes corresponding to desirable traits of rare species in developing better varieties of crop and domestic animals.

Summary

Earth's rich biodiversity is important for our survival. The different plants, animals and microbes provide us all our food, sizable portion of fibers, a lot construction materials for subsistence (consumptive use value of biodiversity) and many tradable (minor and major forests products) materials our economy (productive use value). However, of all species on Earth, we are dependent on very small percentage of species for our consumptive and productive use, though we are exploring our biological treasure (bio-prospecting) for findings new medicines, nutraceuticals, food source and industrial raw materials. Wild plants and animals could be used in developing better variety of crop, horticulture plants and better breed of domestic animals. Bio-prospecting is also the part of productive use value of biodiversity. Biodiversity is also linked with our social customs and rituals and we also derive aesthetic and spiritual pleasure from wilderness areas (social and

aesthetic value of biodiversity). Our love for nature is the base of the ecotourism industry which depends on the rich biodiversity of the region. Even if we do not find any direct benefit from a species still we have no right to destroy its habitat and make it extinct as planet Earth is not just created to humans only, Earth is also home of all other species which have co-evolved with humans. This is called ethical value of biodiversity. Finally all species have some specific role in functioning of self sustaining natural ecosystem (ecological value of biodiversity) and we are dependent on natural ecosystems for many vital services such as food production, waste disposal, climate regulation, freshwater, nutrient cycling, disaster mitigation etc. Natural ecosystems provide us services which are equal to or more than total gross national product (GNP) of all nations. Valuation of ecosystem services is an important aspect of environmental impact assessment of projects related to economic development. Even after our so much dependence on Earth's biodiversity, we are currently losing it at a rate which is 100 times faster than the background rate of species extinction. The four major causes of species loss are: Habitat change, invasion species invasion, overexploitation and co-extinction. Rising population and economic activities of humans are destroying the habitat of species which adapted for specific environmental conditions provided by their natural habitat. Still we can conserve many of our species which are at the verge of their extinction through protecting their habitat through national parks and wildlife sanctuaries (in-situ conservation) and through modern techniques of conservation biology.

Key words

Value of biodiversity, Consumptive use value, Productive use value, Instrumental value, Intrinsic value, Social value, Ethical value, Information value, The Evil Quartet, Habitat change, Alien species invasion, Overexploitation, Co-extinction, Men-wildlife conflict, Ecosystem services, Valuation of ecosystem services, Ecological value, In-situ conservation, Ex-situ conservation, National parks, Wildlife sanctuaries, Biosphere reserve, Captive breeding, Cryopreservation, Cloning

Self assessment

1. Direct utilization of biodiversity by local communities to satisfy their basic needs is known as_____ value of biodiversity.

a) Productive use
b) Aesthetic
c) Ecological
d) Consumptive use

2. Biodiversity provides raw materials to many industries which are recognized as its_____ value.

a) Aesthetic
b) Information
c) Productive
d) Consumptive

3. _____ is a process of discovering new uses of wild species.

a) Eutrophication
b) Bioprocessing
c) Biological prospecting
d) Biomagnification

4. Electric eel can generate a voltage up to 600 V, which could help us to develop biocompatible flexible batteries to run cardiac pacemakers. This importance of a species is known as its _____

a) Aesthetic value
b) Productive value
c) Information value
d) Consumptive value

5. Loss of biodiversity can destabilize an ecosystem. By stability of ecosystem we mean: _____

a) Its species abundance remains constant

b) There is no death of any species
c) Its primary productivity remains constant year on year
d) Its average rainfall remains constant

6. Species which are on the verge of extinction are known as_____ species.

a) Endangered
b) EDGE
c) Endemic
d) Extinct

7. Steller's sea cow got extinct due to _____

a) Over exploitation
b) Alien species invasion
c) Co-extinction
d) Habitat loss

8. _____ is protection of endangered species in its natural habitat.

a) Ex-situ
b) In-situ
c) In-vivo
d) In-vitro

9. Which of the following is an example of ex-situ conservation?

a) National park
b) Wildlife sanctuaries
c) Biosphere reserve
d) Gene bank

10. _____ is a recent DNA technology for ex-situ conservation.

a) Tissue culture
b) DNA fingerprinting
c) Cloning
d) Zoological garden

11. _____ is situated in Himalaya biogeographic zone of India.

a) Gir
b) Kaziranga
c) Corbett
d) Valley of Flowers

12. Periyar national park is situated in _____ biogeographic zone of India.

a) Himalaya
b) North-East
c) Western Ghats
d) Deccan Peninsula

13. A species introduced in a region from _____ is called alien species.

a) Different biological realm
b) Same biological realm
c) Different planet
d) All of the above

14. _____is made of connected national parks and wildlife sanctuaries.

a) Botanical gardens
b) Zoological garden
c) Biosphere reserve
d) Biogeographic zone

15. Amount of ecosystem services reduces with _____

a) Decline of biodiversity
b) Increase of biodiversity
c) Reduction in electricity production
d) Decline of highways and railways services

Answers for self-assessment

1.	D	2.	C	3.	C	4.	C	5.	C
6.	A	7.	A	8.	B	9.	D	10.	C
11.	D	12.	C	13.	A	14.	C	15.	A

Review questions

1. How is Earth's rich biodiversity important for us?

2. Explain the productive use of biodiversity.

3. What is the ecological value of biodiversity?

4. List important ecological services which are derived from Earth's natural ecosystems.

5. Discuss the valuation of ecosystem services.

6. How habitat change impacts biodiversity?

7. What may be the impact of introduction of alien species over biodiversity of a region? Explain with two examples.

8. Discuss the present situation of biodiversity loss.

9. What is in-situ conservation?

10. Explain the cloning method of ex-situ conservation.

11. Explain the causes and impact of overexploitation of biodiversity.

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Unit 07: Environmental Pollution

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Objective

After careful study of this chapter, you will be able to

- know the causes of air pollution.
- understand the mechanism of formation of photochemical smog.
- know what industrial smog is.
- know how air pollution depends on weather conditions.
- know impact of air pollutants on our health including ill effects of fireworks.
- know how we can predict air pollution and its control measures.

Introduction

Environmental pollution is a decline of services (the clean air, safe drinking water etc.) that we derive from our environment. This decline mostly happens due to entry of additional substances or energy called pollutants to various components (atmosphere, hydrosphere and lithosphere) of our environment, in an amount which is harmful to human and other living species. In the present unit and other units following it, we would try to understand how above components of our environment are getting polluted. Let's first learn about the causes of decline of our air quality. We would also try to understand how air pollutants affect our health and how we can reduce the air pollutants to a level which does not harm us.

7.1 What is air pollution?

As per the Air (Prevention and Control of Pollution) Act, 1981, air pollution is said to exist if the levels of gases, solids, or liquids present in the atmosphere are high enough to harm humans, other organisms, or materials. So, any substance (gas, liquid or solid) present in the atmosphere, which affects our health or affects the health of animals and plants or deteriorates buildings or materials, is termed as air pollutant.

1. Case Study: Donora Snog, 1948

Now let us discuss the major air pollution episode which leads to formation of environmental laws related to air pollution in many countries.

Donora is situated near Pittsburg at the bank of Monongahela River in the US. On October 26, 1948 there was a dense fog in Donora. At that time, the town's population was 13,000 and it was an industrial town. The two big industries one steel plant and one zinc reduction plant was successfully running in the town which supported the US economy during World War II by supplying galvanized iron articles like barbed fences, nails and sheets.

The fog was not unusual for the town's people at that time as it generally occurred in the morning and lifted till noon when the Sun arose. But, the fog of Tuesday, 26-Oct-1948 lasted for five days (Fig. 1A). The coal used in steel plant had high concentration of sulfur, while the zinc reduction plant was using sulfur laden ore for extracting zinc metal. These two operations were releasing large amounts of sulfur dioxide in the atmosphere of the town. Due to the above persisting fog on Wednesday and Thursday people started to smell pungent sulfur dioxide in the air. On Friday morning physicians of the town received calls from elderly and asthmatics for difficulty in breathing. However, till evening of Friday even young adults also started to call physicians for suffering from headache, stomach pain and nauseating feelings. On Saturday 10 am first death was reported and by afternoon 20 more people died due to unknown disease. The owners of mills were sure this had nothing to do with operation in their plant, which was plausible as the plant had been running for many decades. Fortunately, Sunday was a holiday and plant operation was halted, mercifully rain also arrived on Sunday which cleared the atmosphere. But still it killed 50 more people in the next month and 6000 people in the town of 13,000, got sickened.

Later investigation found that generation of sulfate particles and their accumulation including the sulfur dioxide (source the source of sulfate particles) due to anticyclone, resulted in so many casualties (Ref. 2, 6).

Figure 1(A) Donora Smog (Source: National Geographic, Ref. 6), (B) Recent Industrial Smog in Beijing city of China (Source: C&EN, Ref. 8).

7.2 Industrial Smog:

The incident which occurred in Donora is called industrial or sulfurous smog. The similar smog also occurred in London in 1952 and recently found in our country and China. The Donora smog incident explains to us that air pollution depends on two factors: weather conditions and emission rate of air pollutants. The industrial smog is characterized by particulate matter (PM, vide infra) of size (0.2 to 0.9 μm) which disperse visible light and causes the disappearance of blue sky (Fig. 1B). The particulate matter could be sulfate or nitrate particles depending on major source emission. Areas which have high concentration of coal fired power plants may suffer from industrial smog dominated by sulfate particles, while areas where the major source of air pollution are automobiles may suffer from industrial smog dominated by nitrate particles.

7.3 Photochemical Smog:

As the application of petroleum products and natural gas replaced the use of more polluting coal, the incidences of industrial smog were minimized. However, the rapid use of petroleum products as transportation fuel resulted in a new type of smog which first occurred in Los Angeles, US. This type of smog observed on clear sunny days, in contrast to industrial smog which mostly formed during foggy weather. A severe photochemical smog incidence turns sky orange, which is different from grayish white sky observed during industrial smog (Fig. 2).

Many secondary air pollutants (such as ozone, aldehydes, ketones, PAN etc.) are formed during incidence of photochemical smog. Let's try to understand the mechanism of photochemical smog formation. As photochemical smog is formed by reaction of nitrogen oxides and volatile organic compounds or VOC (gasoline, methane, acetone, isoprenes etc.), we would first discuss what the major air pollutants are.

Figure 2 A smoggy view of skyline of Bangkok (Source: Science, Ref. 7)

2. Why does the sky look orange during photochemical smog, while grayish white in case of industrial smog?

7.4 Major air pollutants:

The major pollutant whose safe level is given by Central Pollution Control Board of India is given below:

- Carbon Monoxide
- Nitrogen oxides
- VOC
- Ozone
- Sulphur oxides
- Suspended Particulate Matter

3. Carbon monoxide:

It is a toxic gas which is generated during combustion of hydrocarbons in low amounts of oxygen. The complete combustion of hydrocarbons produces mainly CO_2 and H_2O, but incomplete combustion results in formation of CO.

CO forms a stronger bond with hemoglobin than O_2 and stops the ability of blood to supply O_2 to various tissues of our body. Impact of CO on our health depends on how much carboxyhemoglobin is formed in the blood after staying in an environment possessing CO.

The percentage of carboxyhemoglobin generated in our blood is given by following expression:

$$\%COHb = \beta(1 - e^{-\gamma t})[CO] \quad (1)$$

Here, β = 0.15% per ppm of CO

γ = 0.048 per hr (hour)

[CO] = concentration of CO in ppm.

From the above equation (1) it is clear that impact of CO depends on not just concentration of CO in the atmosphere, but also on how much time we spend in a polluted atmosphere.

4. Nitrogen oxides (NOx):

There are seven nitrogen oxides known in literature, but from air pollution perspective two are important, nitric oxide NO and nitrogen dioxide NO_2. There are two sources of nitrogen oxides. First is the direct reaction of N_2 and O_2 (Eq. 2) in IC engines where temperature is above approximately 800°C. This is called thermal NOx.

$$N_2 + O_2 \rightarrow 2NO \quad (2)$$

Another source is nitrogen contained in fuels, which is converted to NOx during combustion and called fuel NOx. Most of the nitrogen oxides emitted in the form of nitric oxide NO from the source. It is readily converted to NO_2 after its emission in the atmosphere (Eq. 3).

$$2NO + O_2 \rightarrow 2NO_2 \quad (3)$$

NO was found to have no adverse impact on health at concentration present in the atmosphere. NO is an important Gasotransmitter (gaseous messenger molecule) in our body, it is also released by macrophages (part of the immune system) to kill engulfed pathogens. However, NO_2 irritates our lungs (induce bronchitis, pneumonia) and reduces its immunity for respiratory infections.

5. Volatile organic compounds (VOC):

VOC are mostly non-toxic organic compounds emitted from evaporation of fuels and solvents used in paints, varnishes, and industrial processes. These are also emitted into the atmosphere due to incomplete combustion of fuels. VOC are listed as air pollutants as these react with NOx in the presence of sunlight and generate photochemical smog. Let's understand the mechanism of photochemical smog formation.

7.5 Mechanism of formation of photochemical smog:

NO_2 is a brown colored photoactive gas responsible for the reddish brown color of photochemical smog. It is broken down by photons of sunlight and creates a NO_2-NO-O_3 cycle (Eq. 4-6).

$$NO_2 + h\nu \rightarrow NO + O \quad (4)$$

$$O_2 + O \rightarrow O_3 \quad (5)$$

$$O_3 + NO \rightarrow NO_2 \quad (6)$$

In this cycle initially generated NO_2 leads to formation of ozone O_3 which is broken down by NO. As per experiments done in laboratory smog chambers, this cycle does not produce O_3 concentration which is harmful to humans. It is the introduction of hydrocarbons (VOC) which disturb the above cycle and increases the concentration of O_3 in the atmosphere, as shown below.

$$R\text{-}CH_3 + OH\cdot \rightarrow R\text{-}CH_2\cdot + H_2O \quad (7)$$

$$R\text{-}CH_2\cdot + O_2 \rightarrow R\text{-}CH_2\text{-}O\text{-}O\cdot \quad (8)$$

$$R\text{-}CH_2\text{-}O\text{-}O\cdot + NO \rightarrow R\text{-}CH_2\text{-}O\cdot + NO_2 \quad (9)$$

$$R\text{-}CH_2\text{-}O\cdot + O_2 \rightarrow R\text{-}CHO + HOO\cdot \quad (10)$$

$$HOO\cdot + NO \rightarrow NO_2 + OH\cdot \quad (11)$$

As shown in equations (9) and (11), nitric oxide (NO) which destroys O_3 is consumed, while NO_2 increases due to presence of hydrocarbon and NOx both in the atmosphere. It increases O_3 concentration in the atmosphere. It also leads to generation of lachrymatory aldehydes and ketones in the atmosphere which creates irritation in our eyes during incidence of photochemical smog (Eq. 10). Hydroxyl free radicals which are naturally present in the atmosphere are important species to clean our atmosphere. These radicals convert the pollutants entering in our atmosphere to CO_2, H_2O or water soluble compounds (H_2SO_4, HNO_3 etc.). Now the aldehyde formed in photochemical smog further react with hydroxyl free radicals and oxygen to generate peroxyacyl free radical which react with nitrogen dioxide and form eye irritant peroxyalkyl nitrate (Eq. 12-14), for R=CH3 it is called peroxyacetyl nitrate (PAN). Aldehydes, ketones, PAN and O_3 which are formed during

photochemical smog are collectively called photochemical oxidants. Severity of photochemical smog is measured in terms of O_3 present in the atmosphere.

$RCHO + OH\cdot \rightarrow RCO\cdot + H2O$ (12)

$RCO\cdot + O_2 \rightarrow RC(O)OO\cdot$ (13)

$RC(O)OO\cdot + NO_2 \rightarrow RC(O)OONO_2$ (14)

7.6 Particulate matter and its impact on health:

Particulate matters are fine particles solid or liquids dispersed in the atmosphere, also called aerosol. Depending on size, particulate matters are classified as PM_{10} and $PM_{2.5}$. The examples of particulate matter are dust (dispersion of solids in air), fumes (formed by condensation of vapor), mist, fog (water dispersed in air) and smoke (carbonaceous matter dispersed in air). Only particulate matter having size in the range 0.4 µm to 10 µm are harmful to us. As particulate matter above diameter 10 µm are easily stopped at the upper respiratory tract and those below 0.5 µm follow the air path when we inhale the air and return back when we exhale the air back. However PM, having diameter in the range 0.5 µm to 10 µm, enters our lungs when we inhale, but mostly does not come back from lungs settled inside lungs by sedimentation.

Depending on size, particulate matters are classified as PM_{10} and $PM_{2.5}$. The particulate matters (PM) having size between 2.5 µm to 10 µm are referred as PM_{10}, while PM having diameter 0.5 to 2.4 µm are referred as $PM_{2.5}$. $PM_{2.5}$ are more injurious to health than PM_{10} as they can enter to alveolar sacs of our lungs and may inflame the lung tissues (Fig. 3). It also aggravates asthma, and irritation of airways. Soot and smoke also contain polynuclear aromatic hydrocarbons (PAH), many of them such as benz[a]pyrene is a known human carcinogen. Further, the cytokines released due to lung inflammation were also found to damage the brain leading to dementia and Alzheimer disease. The damage to lung tissue also affects functioning of the cardiovascular system (due to decrease of lung function) leading to cardiac disorders like congestive heart failure and non fatal heart attacks. (Ref. 5).

Do you know? On average we inhale 12 kg of air daily. So, even a very small amount of pollutants in air can have huge impact on our health.

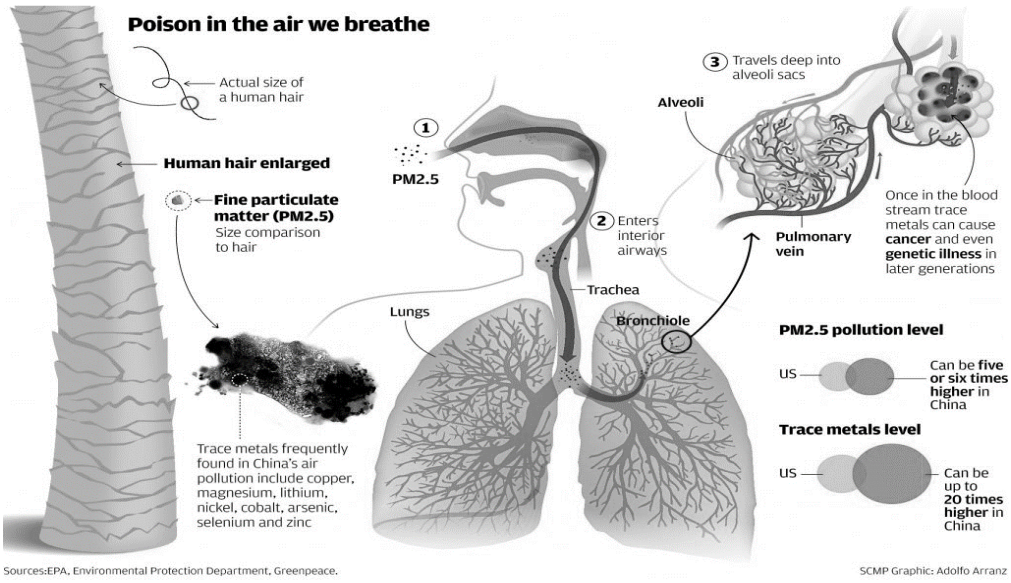

Figure 3 Impact of particulate matter on health (Source: EPA)

7.7 Air pollution and meteorology:

Air pollution not just depends on emission rate from source, but it also depends on prevailing weather conditions. One of the weather conditions which traps air pollution during no horizontal wind flow is temperature inversion. Now the question is: what is temperature inversion? Normally as we move to higher altitude temperature declines, so high mountain peaks are mostly covered with snow. Rate of decrease of temperature with altitude is called the lapse rate. Theoretically the lapse

rate for dry atmospheric conditions is 9.76 ^{o}C/km i.e. temperature declines by approximately 10 ^{o}C temperature as me moves 1 km above in atmosphere. Temperature inversion occurs when instead of decline of temperature it rises as we move up.

The hot exhaust gases coming out from tailpipes and smokestacks of industrial plants move up (because these are less dense than surrounding air) and in this process they cool down due to their expansion in the upper atmosphere since the atmospheric pressure declines as we move up. If the ambient air temperature remains less than the moving up exhaust gases, these gases containing pollutants will move up continuously. However, due to temperature inversion moving up, exhaust gases encounter hot air in the upper atmosphere, which bounce them back to the ground surface. In other words, warm upper air works as a lid for vertical dispersion of air pollutants. Temperature inversion generally occurs during winter months as land cools faster than the upper atmosphere. The temperature inversion becomes more significant in the valley as cool air over mountain surfaces rolls down in the valley (Fig. 4A).

6. Why does the sky turn orange during photochemical smog, even if NO2 emission in the atmosphere remains the same?

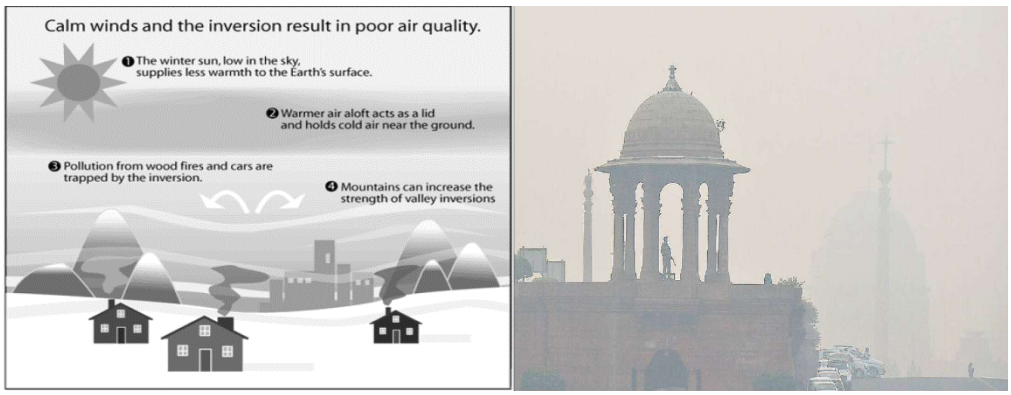

Figure 4 (A) Temperature inversion and air pollution (Source: EPA), (B) A view of Rashtrapati Bhavan in New Delhi on 5-Nov-20 (Source: Hindustan Times)

7.8 Air pollution prediction and its control measure:

We can predict the concentration of air pollutants for a given emission rate and prevailing weather condition. A simple method is the Gaussian plume model for the point source. Point source is generally a smokestack of an industrial plant. Highway is regarded as a line source, while an industrial complex having many industries could be regarded as an area source. For a point source as per Gaussian plume model concentration of pollutant C(x, y) at point (x, y) could be:

$$C(x, y) = \{Q/(\pi.u_H.\sigma_z.\sigma_y)\}.\exp(-H^2/2\sigma^2_z).\exp(-y^2/2\sigma^2_y) \quad (15)$$

Here,

C(x, y) = concentration at ground-level at the point (x, y), µg/m^3

x = distance directly downwind, m

y = horizontal distance from plume center line

Q = emission rate of pollutants, µg/s

H = effective stack height, m

u_H = average wind speed at the effective height of the stack, m/s

σ_y = horizontal dispersion coefficient, m

σ_z = vertical dispersion coefficient, m

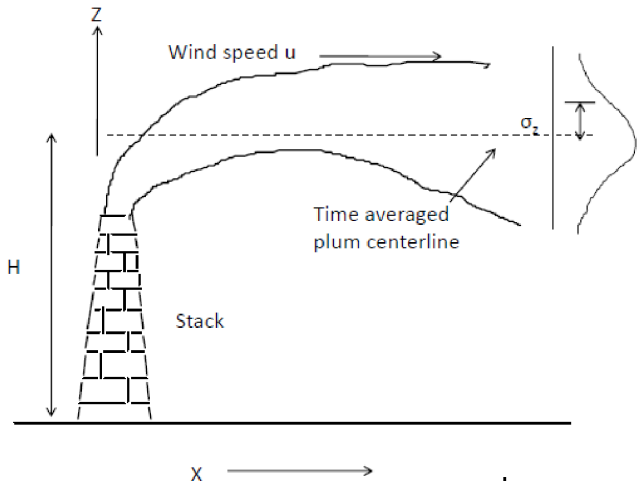

Figure 5 Gaussian plume model of point source of pollution (the y-axis is vertical to plane of paper).

From equation 15, it is clear that the concentration of pollutants is dependent on emission rate from source and weather condition since value of dispersion coefficients σ_y and σ_z depends on weather condition or stability of atmosphere (temperature inversion makes the atmosphere stable). Since we cannot control the stability of the atmosphere, we may control the air pollution (maintain air pollutants at safe level, See Table 1)) by controlling emission rate Q.

It could be done either using improved technologies for combustion or simply removing the air pollutants from exhaust gases. Other options are restricting the source of pollution like implementing an even-odd formula for vehicles running on roads or temporarily stopping the industrial operation.

Table 1 Air quality standard as prescribed by Central Pollution Control Board (CPCB)

NATIONAL AMBIENT AIR QUALITY STANDARDS

S. No.	Pollutant	Time Weighted Average	Concentration in Ambient Air		
			Industrial, Residential, Rural and Other Area	Ecologically Sensitive Area (notified by Central Government)	Methods of Measurement
(1)	(2)	(3)	(4)	(5)	(6)
1	Sulphur Dioxide (SO_2), µg/m^3	Annual*	50	20	- Improved West and Gaeke
		24 hours**	80	80	-Ultraviolet fluorescence
2	Nitrogen Dioxide (NO_2), µg/m^3	Annual*	40	30	- Modified Jacob & Hochheiser (Na-Arsenite)
		24 hours**	80	80	- Chemiluminescence
3	Particulate Matter (size less than 10µm) or PM_{10} µg/m^3	Annual*	60	60	- Gravimetric - TOEM
		24 hours**	100	100	- Beta attenuation
4	Particulate Matter (size less than 2.5µm) or $PM_{2.5}$ µg/m^3	Annual*	40	40	- Gravimetric - TOEM
		24 hours**	60	60	- Beta attenuation
5	Ozone (O_3) µg/m^3	8 hours**	100	100	- UV photometric - Chemilminescence
		1 hour**	180	180	- Chemical Method
6	Lead (Pb) µg/m^3	Annual*	0.50	0.50	- AAS /ICP method after sampling on EPM 2000 or equivalent filter paper
		24 hours**	1.0	1.0	- ED-XRF using Teflon filter
7	Carbon Monoxide (CO) mg/m^3	8 hours**	02	02	- Non Dispersive Infra Red (NDIR) spectroscopy
		1 hour**	04	04	
8	Ammonia (NH_3) µg/m^3	Annual*	100	100	-Chemiluminescence
		24 hours**	400	400	-Indophenol blue method

7.9 Ill effects of fireworks:

Firecracker contains metal salts and gunpowder. Gunpowder works as propellant in a firecracker and metal salt provides a different color to flame. Gun powder is made of KNO_3 (75%), S (10%) and charcoal C (15%). Potassium nitrate (KNO_3) functions as oxidizer, charcoal works as fuel and S reduces the ignition temperature. Metal salts used in firecrackers are Mg (white color), Rb (violet red), Ti (silver) and Sr (red) salts etc. However, combustion of firecrackers produces NO_2 (from KNO_3), SO_2 (from S) and particulate matter (soot and metal salts) in the environment. All of the combustion products emitted from firecrackers are major air pollutants. As discussed above NO_2 is known to decline immunity of our lungs and particulate matter, especially PM2.5 enters deep inside our lungs and excess can lead to inflammation. The concentration of these pollutants is enhanced to a very high level during festival season. This was the reason that Supreme Court of India banned use of fire crackers during Diwali month (Nov-2020) in many metro cities including Delhi, as decline of lungs immunity could lead to rise of death rate due to COVID-19.

Case Study 2: Poor air quality in national capital

On Wednesday, 5-Nov-2020 New Delhi's air quality index (AQI) deteriorated to 386 (very poor category). The residents of Delhi woke up with a thick blanket of smoke hanging over in atmosphere. It was caused due to anti-cyclonic condition over Delhi which pushed back smoke coming from stubble burning in Punjab and Haryana states to subside over Delhi. The low wind speed was also not able to blow away the pollutants. These two factors contributed to accumulation of particulate matter in air of Delhi.

Summary:

Two types of severe air pollution, industrial smog (or just smog) and photochemical smog are formed from reactions of primary pollutants emitted from various sources in the atmosphere. Concentrations of air pollutants depend not on the rate of emission from source, but also on prevailing weather conditions. Temperature inversion is one of the important weather phenomena responsible for trapping air pollutants generated in the atmosphere. We may model the concentration of air pollutants using the Gaussian plume model and its extensions. This helps us in not exceeding air pollution above safe level. Air pollution could be controlled by either inherently safe technologies for combustion or manufacturing or using efficient scrubbers for removing air pollutants from air. If nothing is available, then we can temporarily stop the operation of polluting sources.

Keywords:

Photochemical smog, Industrial smog, Temperature inversion, Major air pollutants

Self-Assessment

1. Which of the following is a secondary air pollutant?

(a) CO

(b) CO_2

(c) O_3

(d) NO

2. Major pollutant in industrial smog is:

(a) Dust

(b) Mist

(c) Sulfate particles

(d) Oxygen

3. Reddish brown color of photochemical smog is due to:

(a) N_2

(b) CO

(c) NO_2

(d) SO_2

4. The source of acetaldehyde in photochemical smog is:

(a) Ethane

(b) Water

(c) Propane

(d) Methane

5. Temperature inversion is said to exist when temperature……with altitude.

(a) Decreases

(b) Increases

(c) Flows

(d) Both (a) and (b)

6. Which of the following is one of the reasons for temperature inversion?

(a) Flood

(b) Cyclone

(c) Anticyclone

(d) Cold wave

7. In a still air temperature inversion stops…….. dispersion of air pollutants.

(a) Horizontal

(b) Downward

(c) Vertical

(d) Aqueous

8. Which of the following air pollutants stops oxygen carrying capacity of blood?

(a) N_2

(b) CO_2

(c) CO

(d) H_2O

9. Which of the following particulate matter types present in air have the most deteriorating effect on our health?

(a) Fog

(b) PM2.5

(c) PM10

(d) Sand particles

10. PM10 denotes particulate matter of diameter between……µm.

(a) 100-10

(b) 2.5-10

(c) 0.4-2.5

(d) 200-100

11. Metal slats are used in fire crackers to create……..

(a) Sound

(b) Temperature

(c) Colorful flame

(d) All of the above

12. Use of firecrackers generates NO_2 in air due presence of…….in gunpowder.

(a) KNO_3

(b) S

(c) Charcoal

(d) NaCl

13. Bursting of firecrackers generates SO_2 in air due to the presence of……..in gunpowder.

(a) KNO_3

(b) Charcoal

(c) S

(d) K_2CO_3

14. Ground level concentration of an air pollutant could be reduced by…….. of smokestack.

(a) Decreasing height

(b) Increasing height

(c) Increasing strength

(d) Decreasing diameter

15. During temperature inversion we can control air pollution by……

(a) Reducing air moisture

(b) Reducing wind speed

(c) Reducing emission rate of air pollutant

(d) Reducing air temperature

16. Temperature inversion in valleys becomes more severe due to…….

(a) Low temperature on mountain

(b) Low atmospheric pressure in valleys

(c) Roll down of cool air to valley

(d) Upward movement of cool air in valley

17. One of the mitigation strategies to reduce air pollution in metro cities is:

(a) Use of electric vehicle

(b) Work from home

(c) Closure of all industries

(d) All of the above

7. Answers

1.	(c)	2.	(c)	3.	(c)	4.	(a)	5.	(a)	6.	(c)
7.	(c)	8.	(c)	9.	(b)	10.	(b)	11.	(c)	12.	(a)
13.	(c)	14.	(b)	15.	(c)	16.	(c)	17.	(a)		

Review Questions:

1. What is industrial smog? Explain its formation.

2. Write the mechanism of formation of photochemical smog.

3. What is temperature inversion? How does it affect air pollution?

4. Explain the factors affecting the concentration of air pollutants in the atmosphere.

5. Explain the air pollution caused by fireworks.

6. What are particulate matters? Explain their impact on human health.

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Unit 08: Environmental Pollution

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Objectives

After completion of this chapter, you will be able to

- know about water pollutants responsible for killing our water bodies and affecting our health.
- understand what biomagnification and eutrophication are.
- know how to treat wastewater before discharging it in water bodies.
- understand how noise is measured.
- know the impact of noise on our health and its control measures.

- know factors responsible for polluting our soil.
- know nuclear hazards associated with nuclear energy use.
- understand the causes of nuclear accidents.

Introduction

Water, a vital resource for human survival and economy, flows in cycle. The hydrological cycle is made of three sub-cycles or loops which are: evapotranspiration loop, surface runoff loop, and groundwater loop as discussed in unit 3. For our freshwater requirement, we are dependent on surface runoff and groundwater loops. The freshwater is obtained from surface and ground water sources. Whatever freshwater which is consumed is finally converted to wastewater with some loss of water in evaporation. The wastewater discharged back to the same surface water sources. Some wastewater directly and some indirectly (through surface water bodies) percolates in groundwater. Now, since water flows in a cycle it is very important to treat the wastewater before its discharge in surface water bodies. Discharge of untreated and poorly treated wastewater in water bodies leads to pollution of aquatic ecosystems and affects human health if polluted water somehow enters the drinking water system. In this unit, we would discuss water pollutants, their impact on human health and on aquatic ecosystems, and how we can remove water pollutants from wastewater before discharging it to water bodies.

Noise is another pollutant which affects our atmosphere. Noise is energy (sound energy) dispersed in the atmosphere and it is different from other air pollutants which are matter dispersed in the atmosphere. In this unit we would also learn about how noise is measured, its impact on our health and what is the safe noise level including some developments which could help us in creating a low noise atmosphere. Next topic of discussion is soil pollution where we would discuss how different soil pollutants impact the fertility of soil. The chapter will end with discussion on the causes and impact of nuclear hazards on human health.

Ganga Pollution

Ganga is considered the holiest river of India. The river is cradle of Indian civilization from the time immemorial. People have so much belief in healing and rejuvenation power of the river that its water is used for drinking without any purification in many rituals. The river supports population of five Indian states in which three (Uttar Pradesh, Bihar, and West Bengal) are densely populated. Many major cities such as Haridwar, Narora, Kanpur, Prayagraj, Varanasi and Patna are situated at the bank of the river. The deep channel of the river and high bank also protects many cities (e.g. Varanasi) at the bank of the river from flood. However, even though it's so important in Indian culture, the river is also suffering from pollution like so many other rivers of the country.

During lean season some stretches of Ganga become unfit even for bathing (Fig. 1). Daily 3000 mld (millions liter per day) of sewage water is discharged in the main stem of river from Class I and II towns which constitute 80% of wastewater discharged in the river. But, till now installed sewage treatment plants are only able to treat 1000 mld of wastewater. Though, the industrial effluents only constitute only 20% of wastewater discharged in the river but due to its toxic nature and non-biodegradability, it has much more impact on river ecosystem and water quality. The industries situated in the catchment of Ramganga and Kali rivers (tributaries of Ganga) and in Kanpur are the major contributors of industrial effluent discharged in the river.

(A)

(B)

Figure 1. (A) Polluted portion of the Ganga near Kanpur (Source: Hindustan Times), (B) The unpolluted stretch of the Ganga (Source: Sodha Travel).

The industrial effluents which are discharged in the Ganga are mainly originated from: (1) Food processing industries, (2) Fertilizer manufacturers, (3) Pharmaceutical industries, (4) Electroplating industry, (5) Textile and paper industries, (6) Tanneries, (7) Oil refineries and petrochemical industry, (8) Sugar and distilleries, (9) Chlor-alkali industries. The waterborne diseases mainly caused due to discharge of untreated domestic wastewater (sewage) in the river is responsible for 80% of all health problems and one third deaths in people dependent on the river water. Sewage water and industrial effluents are point sources of pollution in the river. There are also non-point sources which are also polluting the river (Fig. 2).

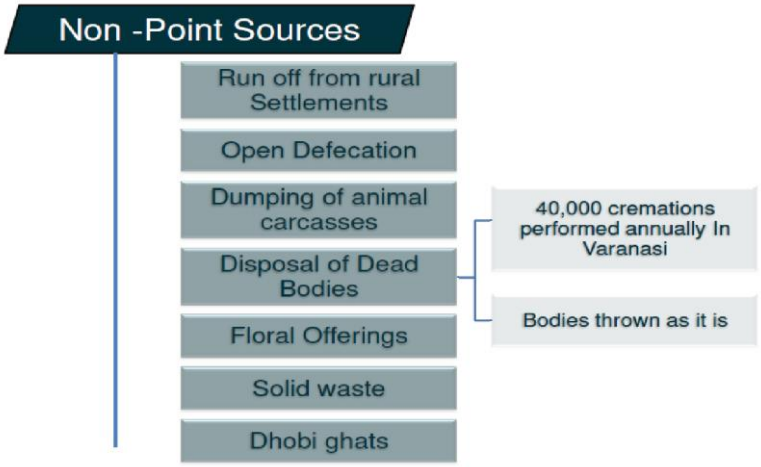


Figure 2. Non-point sources of pollution affecting River Ganga. (Source: Ref. 1)

Exponential population growth induced urbanization and rapid industrialization and rising living standards are responsible for increase of pollution level in Ganga. [1] Let us understand what water pollutants are, what are their impact and how could we remove them from the water cycle (surface and groundwater loops).

8.1 Water Pollutants

Water that is withdrawn for some purpose is returned in the form of wastewater containing different types and amounts of water pollutants depending on its use. For example, agricultural return water contains fertilizers, pesticides, and salts; domestic return water contains human waste, pharmaceuticals, detergents; power plants return water only elevated in temperature while industrial return water may contain many different types of pollutants depending on the nature of industry. Pollutants not just enter in water through aqueous route only, these are also added in water through non-aqueous routes such arsenic, fluoride, and antimony enter in water through mineral deposits, while the major source of mercury in water is exhaust gases coming from coal combustion.

The list of water pollutants is quite lengthy. However, we can classify water pollutants in the following major categories.

8.2 Pathogens

Pathogens are significant water pollutants which enter in water mostly from human and animal fecal matters. These pathogens are responsible for outbreak of waterborne diseases when drinking water, food and recreational water gets contaminated with human sewage or agricultural runoff. The pathogens which spread through contaminated water belong to four classes: virus, bacteria, protozoa, and helminths. Table 1 lists the typical waterborne diseases (also termed infectious diseases) and their causative agents which spread from contaminated water.

Table 1: Some waterborne diseases and their causative pathogens

Pathogen class and name	**Associated disease**
Virus	
Adenoviruses	Respiratory, eye infection
Enteroviruses	
Polioviruses	Aseptic meningitis, poliomyelitis
Echoviruses	Diarrhea, respiratory infections
Hepatitis A virus	Hepatitis
Other viruses	Gastroenteritis, diarrhea
Bacterium	
Salmonella typhi	Typhoid fever
Salmonella paratyphi	Paratyphoid fever
Shigella species	Bacillary dysentery
Vibrio cholera	Cholera
Protozoa	
Entamoeba histolytica	Amoebic dysentery
Giardia lambia	Diarrhea
Cryptosporidium species	Diarrhea
Helminth	
Ancylostoma duodenale (Hookworm)	Hookworm
Ascaris lumbricoides (Roundworm)	Ascariasis
Schistosoma mansoni (Blood flukes)	Schistosomiasis (bilharzia)
Strongyloides stercoralis (Threadworm)	Strongyloidiasis

Many of these diseases such as cholera and typhoid were the cause of epidemic epidemics till the early nineteenth century. After discovery of causative pathogens and linkage between sewage, drinking water and food by John Snow, Louis Pasteur etc., we have been able to control many of the waterborne diseases. The separation of sewage and drinking water systems, development of septic tanks and domestic wastewater and chlorination of drinking water helped in great ways in control of epidemic outbreaks of waterborne diseases.

Most of the waterborne diseases spread through ingestion of water contaminated with sewage, some can infect us by just contact of contaminated water such as helminthic parasites causing Schistosomiasis and Strongyloidiasis. Some protozoa such as *Cryptosporidium parvum* and *Giardia lamblia* form cysts which make them resistant to being killed by chlorine or even with chlorine dioxide. Contamination of drinking water supply by these protozoan cysts resulted in the recent outbreak of cryptosporidiosis and giardiasis in the US.

8.3 Oxygen Demanding Waste or Organic Waste

The biodegradable waste which oxidizes in the receiving water body is called oxygen demanding waste. The biodegradable waste is used as food by aerobic bacteria. However, the discharge of the excess waste results in decline of dissolved oxygen (so the name is oxygen demanding waste) in water bodies with adverse effects on all aquatic animals. We would discuss in detail the impact of oxygen demanding waste on the water body in section 8.3.

8.4 Salts and Heavy Metals

When water percolates and flows through soil and bedrock it dissolves a lot of salts. Salts are water soluble ionic solids which are generally non-toxic to humans except at very high concentrations. Water soluble salts are typically made up of cations such as sodium, potassium, calcium and magnesium and balancing anions are made up such as chloride, sulfates, and bicarbonates. The concentration of salt in water or its salinity is measured in terms of total dissolved solid (TDS) of water.

Salinity of water is an important parameter for its usefulness. For drinking water, the recommended maximum TDS is 500 ppm (mg/L), and when TDS of water increases to 1000 ppm most people recognize the salty test of water. Animals can tolerate higher salt concentration. For example, upper limit of salinity for poultry is 2860 ppm and for cattle it is 10100 ppm. For crops up to 1500 ppm of TDS in soil water is tolerated with little loss in crop yield.

Salinity of water bodies, especially rivers, increases due to withdrawal of freshwater for irrigation projects. As the freshwater is withdrawn less water is left for dilution of salt. Further, water which is used for irrigation returns back to water bodies by dissolving more salt and contributing to the rise of salinity in downstream portions of rivers.

Heavy metals are metals which have specific gravity (density with respect to water) in the range of 3-4. Heavy metals are also present in water in form of their soluble salts, but these salts are made of cations of heavy metals which are often toxic at few ppm concentrations. Most of the heavy metals such as zinc, cadmium, mercury, manganese, chromium, cobalt, nickel, selenium, strontium, aluminum, tin, and lead are toxic. But from an environmental perspective four important heavy metals are: mercury (Hg), cadmium (Cd), lead (Pb) and arsenic (As).

Heavy metals which are considered as essential nutrients such as iron and copper also become toxic when ingested in very high concentration. Cd, Pb and mercury are nephrotoxins which damage the kidney during their elimination from the body. The toxicity of heavy metals depends on their form (ionization state) and mode of ingestion. For example, Hg, a liquid metal when ingested have almost no impact on human health, however, if the vapor of the metal is inhaled then they can damage neurons of the central nervous system after diffusing to blood from lung. Similarly, vapor of Pb metal has no effect on us, but lead in Pb^{2+} which is soluble in blood transferred can easily reach to vital organs and especially affects brain and kidney. Pb^{2+} can also pass from pregnant women to her fetus and severely affects the rapidly growing brain of fetus including children under age five.

Industries and mining and landfill sites are sources of heavy metals in water. The disposal of heavy metals after their removal from water is also problematic since metals are non-degradable. For example, after removal of arsenic from water by immobilizing in another form can be mobilized again if these are disposed of in landfill by their dissolution in acidic landfill leachate. The arsenic through landfill leachate can move to the wastewater treatment system and from there it may gain access to drinking water if not removed from wastewater.

8.5 Pesticides

Pesticides are chemicals which are used for getting rid of species which are harmful or destructive for humans. Four classes of pesticides are commonly used: (1) herbicides for killing weeds (unwanted plants), (2) insecticides needed to kill insects, (3) fungicides to kill different fungi, (4) rodenticides for killing rats and other rodents.

Chemically, there are three classes of pesticides: (1) organochlorine compounds such as DDT, (2) organophosphates such as malathion, (3) carbamates such as aldicarb. The popular 'organochlorine compound' DDT (*p*,*p*'-dichlorodiphenyltrichloroethane) is credited with saving millions of lives

since its effectiveness in killing disease carrying insects such as malaria (mosquitoes), typhus (body lice), and plague (fleas). Methoxychlor, chlordane, heptachlor, aldrin, dieldrin, endrin, endosulfan and Kepone are other widely used organochlorines. However, animal studies found that many of these are associated with liver cancer (dieldrin, heptachlor, and chlordane) or cause birth defects (aldrin, dieldrin and endrin). Further, organochlorines are associated with biomagnifications in food chain which we shall discuss in section 8.5.

The long term effects of organochlorines on humans and their potential for biomagnifications have replaced this class of pesticides with '*organophosphates*'. In contrast to organochlorines, organophosphates are acutely toxic to humans but do not persist in the environment. Popular organophosphates such as parathion, malathion, diazinon, TEPP (tetraethyl pyrophosphates) and dimethoate are used to eradicate a wide range of insects. Humans exposed to excessive amounts of organophosphates show symptoms of acute toxicity which include tremors, confusion, slurred speech, muscle twitching and convulsion.

The 'carbamates' are derivatives of carbamic acid (NH_2COOH). Like organophosphates these are also acutely toxic but do not persist in the environment. Popular carbamates pesticides are carbaryl (was manufactured in the Bhopal plant of Union Carbide), propoxur, and aldicarb. An excess pesticide settles in soil and from there it moves to surface and groundwater.

Chlorophenoxy compounds 2,4-D (2,4-dichlorophenoxyacetic acid) and 2,4,5-T were used in the Vietnam War as defoliants. The mixture of two compounds is called Agent Orange. It can kill broad leaves without affecting grasses. It is used in controlling excess growth of aquatic plants in lakes and reservoirs.

8.6 Emerging Contaminants

There were 239,000 regulated chemicals in 2006 as mentioned in CAS (Chemical Abstract Services) registry. Of which production of 4,800 chemicals exceeded more than 1000 ton/year. From the ever-growing list of new chemicals entering our environment, how can we identify potential environmental pollutants? We can identify emerging contaminant based on criteria of: (1) environmental persistence, (2) toxicity or deleterious impact on both human and non-human creatures, (3) occurrence frequency (number of times a chemical/pollutant occurs in collected sample in a specified period) and concentration, (4) immediacy of impact. Identification of emerging contaminants depends on advancement in instrumentation, sampling, and analytical techniques.

Most important emerging contaminants are *endocrine disrupting chemicals* (EDCs). After installation of genetic code, the development, metabolism and behavior of organisms depends on complex hormone-based chemical signaling controlled by the endocrine system. Endocrine disrupting chemicals interfere with natural functioning of the endocrine system by either being or acting as natural hormone, interfering or blocking function of natural hormone, increasing or decreasing secretion of natural hormone. Exposure to EDCs has been found to be the cause of hermaphroditism (presence of both male and female reproductive organs in a single species), impaired survival and development of offspring of frogs, salmon, oysters, newts, trout, and turtles. For example, in one study of Columbia River 84% of female Chinook salmon was found to be chromosomally male.[2] Gender of fish is plastic which could be altered by exposure to gender bending chemicals or EDCs. Gender disruption in fishes is also responsible for decline of fish population. Two most important EDCs are estrogenic compounds 17β-estradiol (a natural female sex hormone) and ethinylestradiol (derivative of 17β-estradiol used as birth control pill) which have shown to affects reproduction and development of fishes and amphibians. EDCs and other pharmaceuticals enter the human sewage through excretion and disposal of expired drugs by flushing them in the toilet.

Though there is no firm evidence of effects of EDCs on human health, it has been suspected that EDCs are linked with low sperm counts and increased incidence of breast and reproductive organ cancers. Some other significant EDCs are bisphenol A, polybrominated diphenyl ethers (PBDE, a flame retardant), perfluoroalkyl carboxylate (PFCA), DDT, phthalates, and dioxins.[3]

Another emerging contaminant class is nanoparticles. Nanoparticles are now found in paints, surface coating, and also used as food additives (as colorant and preservative), industrial catalysts, and in personal care products (liposomal vesicles). Nanoparticles are emerging materials and basic study about the environmental impact of nanoparticles, or their transformation products is currently going on.

8.7 Oxygen Demanding Waste and Rivers

Dissolved oxygen (DO) is a very important parameter of water quality, since all aquatic biota depend on oxygen dissolved in water for their survival. When oxygen demanding waste (biodegradable waste) is discharged in a water body (river or lake), it works as food for aerobic bacteria. The aerobic bacteria consume the organic waste and form stable non objectionable end products (Equation 1). However, during consumption of organic waste these aerobic bacteria also consume oxygen dissolved in water which depends on the amount of organic waste received by the water body.

$$\text{Organic waste matter (C, H, O, S, N, P)} + O_2 \xrightarrow{\text{Aerobic bacteria}} CO_2 + H_2O + SO_4^{2-} + PO_3^{3-} + SO_4^{2-} \quad (1)$$

Now let us understand what happens when wastewater containing a huge amount of oxygen demanding waste is discharged in a river.

8.8 Biochemical Oxygen Demand (BOD)

Oxygen demanding waste can be measured by determining the amount of oxygen consumed by wastewater. Since complete degradation of organic waste in wastewater may take weeks. The biochemical oxygen demand (BOD) is defined as decline of dissolved oxygen per liter of wastewater within five days by aerobic microbes. BOD is measured in units of mg of oxygen consumed per liter of wastewater or as mg/L which is the same as ppm (parts per million). Often wastewater does not contain enough water for microbes to degrade organic waste, so we have to dilute the wastewater with enough water to maintain required DO. Now, the BOD of wastewater under dilution is given by:

$$BOD_5 = \frac{DO_i - DO_f}{P} \quad (2)$$

where

DO_i is initial dissolved oxygen in diluted wastewater,

DO_f is final dissolved oxygen after five days

P is dilution factor or

$$P = \frac{\text{Volume of wastewater}}{\text{Volume of mixture (wastewater + dilution water)}}$$

We take wastewater in a BOD bottle and dilute it with additional water and measure the initial DO with oxygen electrodes (an electrochemical device based on reduction of oxygen). The BOD bottle is left in the dark for five days and again we measure the final DO of the mixture and then using the Eq. 2 we can estimate the BOD of wastewater. The rate of consumption of organic waste follows approximately first order kinetics and by following the change of BOD of wastewater we can determine the rate of deoxygenation of the water body receiving the waste.

8.9 Effect of Oxygen Demanding Waste on River

The saturated level of DO in a water body depends on many factors (temperature, salinity etc.) and varies from 8 ppm to 15 ppm. The requirement of DO for aquatic species (fishes, amphibians, plants) varies, but for survival of most of the aquatic species DO of a river or other ware bodies it should be at 5 ppm or more. When wastewater with very high BOD is discharged in a river then it starts to consume DO of the river. We can estimate the decline of DO of rivers at various points of river downstream to point source of wastewater, if we know the rate of deoxygenation (due to

decomposition of organic waste) and rate of reaeration. Rate of deoxygenation could be modeled by determining the first order kinetics of BOD change of wastewater. As the DO in river water declines from its saturated value (DO_s), an oxygen deficit is generated which is given by deficit $D = DO_s - DO$. The rate of preparation is proportional to oxygen deficit D. So, we can calculate the DO values of the river at various points downstream the point source. Without going into mathematical details, some typical patterns of DO of river downstream from point source at various value of BOD are shown in Figure 3.

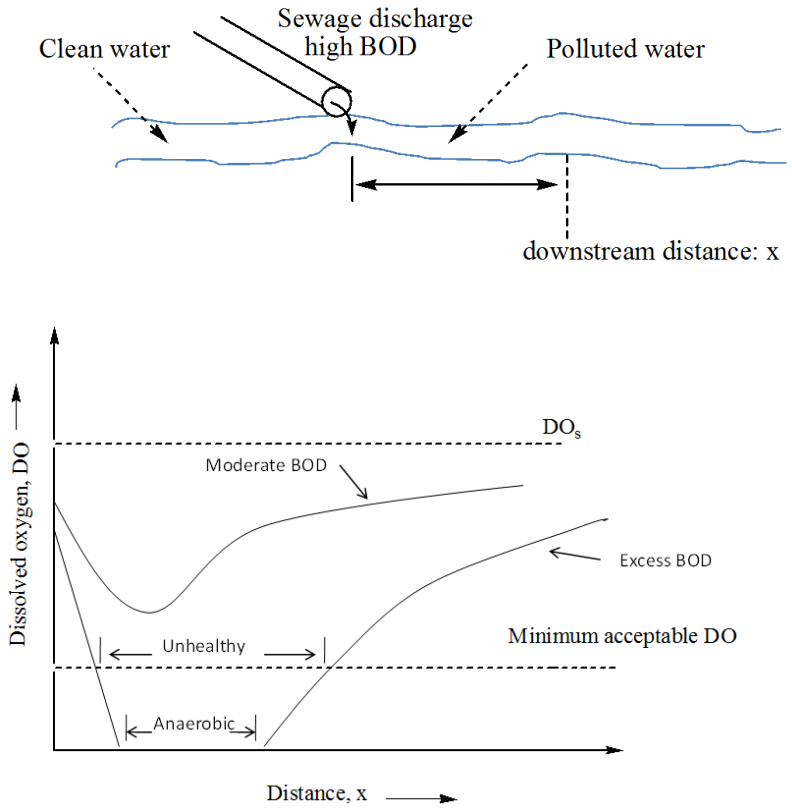


Figure 3. Oxygen sag curve of a river under various values of wastewater BOD. (Ref. [4])

These curves are also called oxygen sag curves. As shown in Figure 3, the DO level reached a minimum value at some distance (called critical point) from the point source. The DO at critical point can be kept above the minimum acceptable DO value, if the BOD of wastewater is reduced to value as estimated by prevailing river conditions before its discharge in the river. However, if untreated or poorly treated sewage or industrial effluents is discharged in the river then oxygen sag curve could drop below the minimum acceptable DO and even reach to zero value of DO. The stretch of the river where DO is below minimum is called an unhealthy segment of river. Unhealthy segment cannot support the rich diversity of aquatic species. Many of the native fishes of the river would either be driven away or die in this segment and they are taken over by less desirable life forms such as thick mats of fungi, filamentous bacteria, and blood worms that blanket the bottom of the unhealthy segment. Under extreme conditions of zero DO, the river becomes lifeless and the segment of river with zero or anaerobic condition is called the dead zone. Decomposition of organic waste also continues in the dead zone, but at a slower rate by anaerobic microbes. The anaerobic decomposition, however, generates noxious and harmful end products such as H_2S, NH_3 (Eq. 3).

$$\text{Organic waste matter (C, H, O, S, N, P)} \xrightarrow[\text{bacteria}]{\text{Anaerobic}} CH_4 + NH_3 + H_2S + \ldots\ldots\ldots \quad (3)$$

Temperature increase also lowers the oxygen sag curve due to increase of microbial decomposition rate and decrease of saturated DO value in water. A river which does not suffer from decline of DO below minimum may show unhealthy DO level in warmer summer months. Similarly, discharge of return water at elevated temperature from thermal power plant may make a stretch of river

downstream of the power plant unhealthy even without any increase of BOD of discharged wastewater.

Photosynthesis also affects DO of water bodies. A lake or slow-moving river already having heavy load of BOD and choked with algae may appears fine during daytime, but late in night we can experience obnoxious gases emanating from the same water body due to respiration same algal population consuming a lot of DO of water body in night time and promoting anaerobic decomposition.

We can preserve sufficient oxygen in rivers by modeling the impact of BOD on it. It could help us in planning and establishment of improved wastewater treatment plants for existing residential and industrial complexes of the city or in relocating them to other locations if current technology cannot support the maximum total BOD tolerated by the river.

Ghaggar River and ground water potability

We may think that a grossly polluted and lifeless river cannot affect our health if we are not using the river water. But it is not possible due to linkage of river and groundwater aquifers (Fig. 4). The water pollutants of rivers can move to unconfined aquifers and increase the concentration of pollutants to a level harmful to human health at least in regions near to riverbank.

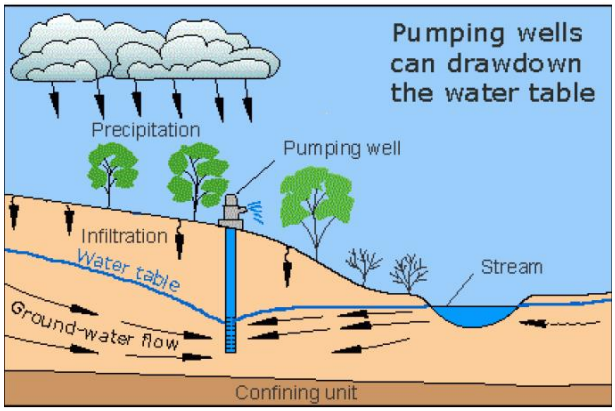


Figure 4. Linkage of aquifers and rivers. (Source: USGS)

The above fact was demonstrated in the suffering of people from hepatitis and blood cancers, living in two dozen villages of Mansa (Punjab) and Sirsa (Haryana) districts which are situated at the bank of Ghaggar River. The river which was used some three decades before for swimming by villagers is now converted to 'nullah' or drain (Fig. 5). The BOD of the river was found to be 24 ppm, while the prescribed BOD by CPCB for use of water bodies for bathing is 3 ppm. [5] The residents of villages were also unable to sleep at night due to foul smell emanating from the river during night. The high pollution level of the river has contaminated the groundwater reserves and people are demanding access to the canal for potable water. The cause of conversion of a natural river to a drain was industrial effluents coming from industries situated in Chandigarh. As we discussed before, water flows in cycles, so it is important to remove all pollutants from wastewater before discharging in natural water bodies for our better health.

Figure 5. Ghaggar River in Sardulgarh town of Mansa district. (Source: Hindustan Times, Ref. 5)

8.10 Nutrients and Lakes

Nutrients are chemicals which provide essential elements such as carbon, nitrogen, phosphorus, sodium, potassium, iron, manganese, cobalt, calcium and magnesium for growth of living species. A species needs some nutrients in large amounts called macronutrients and some are needed in very small amounts which are termed micronutrients. Nutrients are considered water pollutants if they are present in sufficient concentration which could allow algal bloom in still and slow-moving water bodies.

As lakes and reservoirs age they naturally accumulate nutrients and debris which lead to an increase of productivity, a phenomenon called 'eutrophication'. During the eutrophication process, lake water becomes murkier and warmer due to an increase in the population of phytoplankton and absorption of more solar energy. The lake also got shallower as they eutrophy due to accumulation of silt and organic waste. The shallower periphery of eutrophic lake allows colonization of rooted plants which leads to slow conversion of lake to marsh or bog. However, natural eutrophication takes thousands of years. The addition of excess nutrients in lakes, mostly due to human activities, increases the eutrophication process (called cultural eutrophication) with adverse consequences on water quality and aquatic species.

8.11 How Nutrients Cause Algal Bloom?

Algae are photosynthetic species which need sun light and nutrients. Of all nutrients needed for growth of algae; carbon, nitrogen and phosphorus are the major requirements. Sunlight and carbon in the form of dissolved carbon dioxide and bicarbonates are abundantly present for algae. Availability of nitrogen and/or phosphorus in water bodies is mostly limited. Mostly coastal water has limited availability of nitrogen. However, as freshwater lake eutrophy they mostly support blue-green algae '*Cyanophyta*' which have the ability to fix nitrogen directly from the atmosphere, so nitrogen is not a limiting nutrient in older lakes. Only phosphorus is present in limiting amount in lakes which are under process of eutrophication.

As per Leibig's law of minimum, "the growth of a plant is dependent on nutrient which is presented to it in minimum amount". The limited availability of phosphorus controls the growth of algae or algal bloom in freshwater lakes. The natural mechanism of control of algal bloom is destroyed when access to phosphorus entered in P-deficient lakes or excess nitrogen enters in N-deficient lakes or coastal water bodies.

8.12 Impact of Algal Bloom or Eutrophication on Lakes

Most algae have a short lifespan. As the excess algae of lakes die off, they settle in the bottom of lakes and behave as oxygen demanding waste consuming oxygen from an already oxygen deficient 'hypolimnion zone' of lakes. Thermal stratification of deep lakes during summer creates zones of different temperatures since less dense warm water of lake (making zone of higher constant temperature called 'epilimnion') mostly floats over cold-water zone called 'hypolimnion'. The two zones are mostly separated from each other through the presence of an intermediate zone called 'thermocline', where temperature declines sharply with depth. The epilimnion zone of lakes have DO at almost saturation level due to contact with atmosphere and rich supply of oxygen from photosynthetic organisms. However, due to thermal stratification DO values are generally quite low in hypolimnion. The hypolimnion zone supports the Coldwater fishes of the lake. The high supply of dead alga to hypolimnion not only deprives it from DO, thick mat of alga from algal bloom (Fig. 6) also stops penetration of sunlight to hypolimnion cutting another source of oxygen delivered by photosynthesis. Insufficient DO in the hypolimnion zone of lakes becomes the cause of killing cold water fishes. In extreme cases, hypolimnion becomes hypoxic (no oxygen) and promotes anaerobic decomposition of excess BOD generating toxic and obnoxious end products such ammonia, hydrogen sulfide, acetic acid etc. These substances are not only toxic but also make heavy metals soluble in lake water from sediments in the bottom of the lake.

Some algae such as toxic dinoflagellate *Pfiesteria piscicida*, also secretes harmful chemicals. These toxins (e.g. domoic acid) are also found to bioaccumulate in the food chain killing or sickening higher animals including humans (consuming fish and seafood harvested from algal bloom affected water bodies). Dead algae also washed away to shores reducing the aesthetic of the environment.

Figure 6. Brown algal bloom over Dal Lake. (Source: Kashmir Convener)

8.13 Sources of Nutrients

Both point and nonpoint sources contribute nutrients to the water body, but contribution of non-point sources is quite high. In non-point sources agricultural runoff dominates other sources. In addition to excess use of phosphorus in crop production, another major cause of phosphorus addition in lakes is human sewage in which the human fecal matter and biodegradable phosphorus-based detergents are the main contributors of phosphorus. For nitrogen, another significant source is atmospheric deposition of nitrates (contributed by fossil fuel powered automobiles and thermal power plants) in water bodies.

Biomagnification

Many pollutants entering natural water bodies accumulate through the food chain in species at higher trophic level. The pollutant may not be toxic to any life forms at concentration present in the receiving water body, due to their predisposition for bioaccumulation that affects the whole ecosystem. The properties of substances which predispose them for bioaccumulation are: (1) their persistence in the environment due to high stability, (2) their solubility in hydrocarbon solvent which facilitates their accumulation in fatty tissues. Few examples of these substances are DDT, polybrominated diphenyl ethers (PBDEs), perfluroalky carboxylates (PFACs), domoic acid (algal toxin), and dimethyl mercury.

DDT which has no acute toxicity and is an effective pesticide to control mosquitoes has finally entered water bodies where it biomagnified through aquatic food chains. Since birds at the highest trophic level were the worst affected species. The presence of DDT (and its metabolite DDE, dichlorobiphenyl dichloroethylene) at higher concentration in many species of birds (such as peregrine falcons, bald eagle, ospreys, and brown pelicans), interferes with the enzyme involved in distribution of calcium in the birds. This interference of DDT resulted in thinning of their eggshell, which was unable to tolerate the weight of the parent. The disruption of the endocrine system of birds by DDT resulted in decline of their population. As the environmental level of DDT has subsided due to the current ban of DDT in many countries, some of the species (e.g., bald eagle) are now enjoying resurgence in their population.

'Polybrominated biphenyl ethers' (PBDEs) which is used in flame retardants, and 'perfluoroalky carboxylates' (PFACs) which are biproducts generated during Teflon coating and degradation of fluorinated lubricants, have potential of bioaccumulation and disruption of endocrine system. Domoic acid, which is an algal toxin, does not affect invertebrates but its bioaccumulation affects central nervous systems of mammals. 'Dimethyl mercury' was a byproduct generated in production of acetaldehyde in the manufacturing plant of Chisso Company in Minamata of Japan. The byproduct was discharged in Minamata Bay, which accumulated through the food chain and caused neurological disorders in people consuming seafood harvested in Minamata Bay. It is essential that potential of any new chemicals should be studied for bioaccumulation before its introduction in environment.

Wastewater treatment

As water flows in cycle, it is important that we remove all harmful pollutants from wastewater before its discharge in natural water bodies. The treatment of wastewater depends on combinations of

pollutants present in wastewater. For domestic or municipal wastewater, the probable composition of pollutants is given in Table 2.

Table 2: Composition of raw domestic wastewater

Constituent	Concentration (mg/L)
BOD_5	100 -350
COD (Chemical Oxygen Demand)	250 – 1,000
TDS (Total Dissolved Solids)	250 – 1,000
SS (Suspended Solids)	100 - 400
TKN (Total Kjeldahl Nitrogen)	20 - 80
Total Phosphorus (as P)	5 - 20

BOD_5 measures the biodegradable waste present in wastewater, while COD tells us the amount of organic waste which cannot be degraded by aerobic microbes. It is measured by the amount of potassium dichromate ($K_2Cr_2O_7$, strong oxidizer) consumed in oxidizing non-biodegradable waste. The amount of oxidizer is expressed as mg of oxygen needed per liter of wastewater. The total solid present in wastewater is expressed as TDS and SS (Table 2). The difference between TDS and SS is based on a membrane filter having a pore size of 1.7 µm. The solid (containing colloidal and very small, suspended particles) which could be filtered through the membrane filter are called TDS, while unfiltered solid is termed SS (suspended solid). Total Kjeldahl Nitrogen (TKN) is a measure of nitrogen present both as dissolved ammonia and as part of organic waste in wastewater. Given wastewater sample is digested with concentrated sulfuric acid which converts all the nitrogen (present as part of organic waste) to ammonia. The ammonia liberated in the process (called Kjeldahl procedure) is expressed as equivalent of nitrogen (in mg) per liter of wastewater.

Treatment of wastewater is performed in three stages: primary, secondary, and advanced. Primary treatment involves only physical processes of sedimentation, skimming, and filtration to remove settleable, floatable and filterable impurities. As shown in Figure 7, raw wastewater is first passed through a screen made from a steel bar having spaced between 2 cm to 7 cm. It removes large visible substances such as twig, plastic objects from wastewater which may block pumps or narrow pipes downstream. After removal of large impurities, the effluent passes first from a grit chamber (sedimentation tank) with short retention time (20 to 30 sec) removing intermediate size heavy particles such grit and sand. After that, effluent enters the primary clarifier, which is another sedimentation tank but with retention time (time spent by a portion of wastewater in the sedimentation tank) of 1.5 to 3 hours. Primary clarifier removes most of the fine and settleable impurities. All above operations collectively called primary treatment which reduces 50 to 65% of suspended solid and 25 to 40% of BOD_5. Till 1970s, most of municipal wastewater treatment facilities were only limited to primary treatment and after disinfecting the effluents (to remove odors and kill pathogens) the treated water was discharged in water bodies.

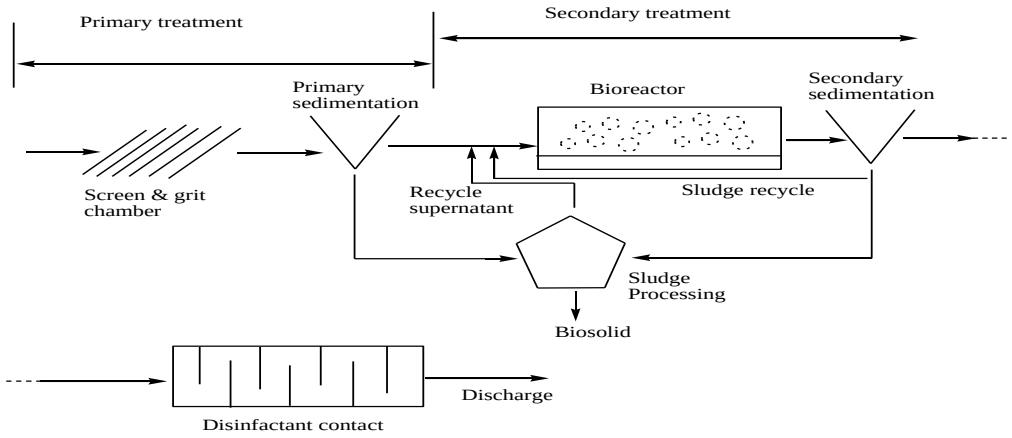


Figure 7. Schematic of a typical wastewater treatment plant. (Ref. 4)

The wastewater after primary treatment still has high BOD, which has the potential to decrease DO of receiving natural water to unhealthy levels. Currently, most wastewater treatment facilities also perform secondary treatment to remove organic waste to acceptable BOD value. Secondary treatment takes help of naturally occurring aerobic microbes to reduce oxygen demanding waste in wastewater. The wastewater after primary treatment is supplied to the bioreactor where favorable conditions for microbial growth are maintained by bubbling enough air to maintain sufficient oxygen in the reactor. The effluent then passes through secondary clarifiers which removes biological slim of microbes. All the sludge generated from primary and secondary treatment is processed separately in an anaerobic digester. A properly maintained secondary treatment is capable of reducing both BOD_5 and suspended solids from wastewater up to 90%.

Secondary treatment can remove a significant amount of suspended solid and BOD from wastewater, but still many dissolved solids such as nutrients and heavy metals or pollutants which is of concern in a given region may be present in wastewater. Removals of these pollutants need 'advanced treatment' which depend on type of pollutant to be removed. Advanced treatment is performed mostly after primary and secondary treatment of wastewater, although in some cases, especially in treatment of industrial effluent only advanced treatment is required.

Measurement of noise

Noise is an air pollutant which is made of residual sound energy in the atmosphere instead of any matter. Noise is measured in decibel (dB). Now what is decibel?

Noise is an unwanted sound. Sound consists of longitudinal pressure waves propagating through an elastic air medium. Like any other wave, the characteristics parameters associated with sound waves are: wavelength (λ), frequency (υ), and speed (c). Sound waves move through compression and rarefaction in air, the distance between two compression zones in air during movement of sound waves is called wavelength of sound. The time for a compression zone to reappear again in the same position during the flow of sound energy is called period (P) of sound wave. The inverse of the period is called frequency of the wave or frequency $\upsilon = (1/P)$. Since the sound travel distance λ (wavelength) in time of period (P), velocity of sound is given by:

$$c = \frac{\lambda}{P} = \upsilon.\lambda \qquad (4)$$

However, the impact of noise is concerned with sound pressure level. Our ear can detect sound pressure as low as 20 µPa (micropascal), and as high as 200 Pa. Sound pressure level is defined as "ratio of square of root mean square pressure of a given sound with respect to square of minimum pressure (pressure of faintest sound) which our ear can detect or 20 µPa". Since this ratio is normally a big number, we express the ratio by taking its logarithm. This quantity is called 'sound pressure level' or simply sound level. Its unit is 'bel', which is named in honor of Graham Bell. A bel is a big unit, so we generally express sound level as decibel (dB) where 1 bel = 10 decibel.

Hence, the expression for sound pressure level in decibel (dB) is:

$$L = 10 \log [(p_{rms})^2/(p_o)^2] = 20 \log [(p_{rms})/(p_o)] \qquad (5)$$

where p_{rms} = root mean square pressure of given sound,

p_o = reference sound pressure which taken 20 µPa

L = sound pressure level

The decibel levels of common sounds are shown in Figure 8.

dB	Environmental Condition
0	Threshold of hearing
10	Rustle of leaves
20	Broadcasting studio

30	Bedroom at night
40	Library
50	Quiet office
60	Conversational speech (at 1m)
70	Average radio
74	Light traffic noise
90	Subway train
100	Symphony orchestra
110	Rock band
120	Aircraft takeoff
146	Threshold of pain

Figure 8. Sound pressure level (in dB) of some common sound. (Ref. [6])

Decibel values cannot be added and subtracted like we add oranges and apples. For example, if a fan produces a noise of 60 dB, then noise level from two same types of fans doesn't become 120 dB since decibel is a logarithmic scale. We should first calculate the ratio of sound pressure from decibel values by taking antilog (Eq. 5). The antilog of sound levels or ratios of pressure values could be summed up. By again taking the log of summed values and multiplying by 20, we can get the answer of adding two decibel values. In our current case, the sum of two noises of 60 dB is: 63 dB. Try to check the answer on your own.

Recognition of a sound as noise depends more on human reaction than on its sound level. The loudness of a sound perceived by humans depends on its frequency (pitch). To account for the above phenomenon, three weighting networks (A, B, and C) were developed which add or subtract additional value to the face value of sound level or dB value of a sound of given frequency. The main difference among them is A- network severely filters very low frequencies, B- network moderately and C- network hardly filters any low frequency. Noise level measured using a specific weighting network is written as dBA (weighted on A- network), dBC (weighted on C-network) etc.

Impacts of noise on human health

We can classify the impact of noise in two categories: auditory effects and psychological effects. Hearing loss and speech interference are two auditory effects of high noise level. Psychological effects include annoyance, sleep interference, and effects on performance.

8.14 Hearing Loss

The most important physical effect of exposure to high noise level is the shift of hearing threshold level (HTL) of a person. The ear of a young healthy individual can recognize a sound till 0 dB for all sound frequencies recognized by human beings. A person living or working in areas having noise level more than 80dBA may suffer from temporary threshold shift (TTS) or permanent threshold shift (PTS). In these shifts of HTL, affected people can recognize instead of 0 dB of a frequency in audible range, but 30 or 40 dB of that frequency. A person suffering from TTS experiences ringing, muffing of sound, or discomfort in years after exposure to high noise level, but can regain to original HTL within days after removal of high noise.

The continuous exposure to noise can convert temporary threshold shift (TTS) to permanent threshold shift (PTS). The cause of hearing loss is decline of hair cells (of inner ear) which convert vibration of perilymph in the cochlear duct (caused by ossicles attached to tympanic membrane or eardrum) to nerve signals.[7] The death of hair cells due to excessive shearing forces caused by very heavy noise or by noise induced high metabolic activity to the point of metabolic failure and consequent cell death.

Intensive noise rarely damages the outer or middle ear. However, explosive sound can rupture the tympanic membrane (eardrum) or can dislocate the ossicular chain. The hearing loss resulting from brief exposure of very loud noise is termed 'acoustic trauma'. The standard safe time limit for exposure to various noises is given in Figure 9.

Duration	dBA
8 hours	90
4 hours	93
2 hours	96
1 hour	99
30 minutes	102
15 minutes	105
7 minutes	108
4 minutes	111
2 minutes	114
1 minute	117
30 seconds	120
Instantaneous rupture of membrane	150

Figure 9. Standard safe time limit for various noise levels. (Ref. 6)

8.15 Speech Interference

Noise that is not intense enough to cause hearing loss, can create a masking effect which causes interference in communications between listener and speaker. The interference caused by noise is a

complicated function of distance between listener and speaker and frequency of sound. Figure 10 explains level of difficulty in communication with respect to background noise and the distance.

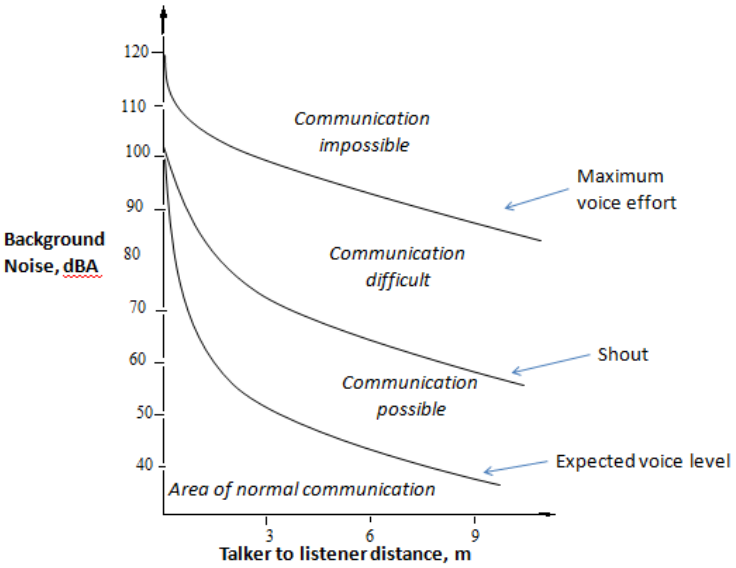


Figure 10. Quality of speech communication depends on distance and sound level. (Ref. [8])

For the distances common for classrooms and living rooms (4.5 to 6 m), normal communication is possible when background noise level is below 50 dBA.

8.16 Annoyance

Annoyance is mostly a psychological effect of noise, though it is also known to affect the cardiovascular system by increasing stress in a person. Annoyance has its base in the unpleasant nature of some sound, and in the activities that are disturbed by noise. For example, a sound at night may be more annoying to us than the same sound heard in day. A sound that fluctuates may be more annoying than sound which remains steady. A sound that is not liked by a person may be more annoying to him than to other people.

One of the most annoying noises is noise generated by aircraft. An aircraft whose speed exceeds speed of sound generates 'sonic booms'. Sonic booms when encountering a person on ground creates a sensation of explosive sound and are very annoying. Supersonic flights are often prohibited over densely populated areas.

8.17 Sleep Interference

The relationship between exposure to sound and quality of sleep is complicated one. A sound can awaken a person or can keep him from falling asleep, but another sound like a soothing lullaby can induce sleep, and perhaps maintain it. A parent can awake from slight stirring from his or her child, but can sleep through the thunderstorm. Possibly, environmental sound can disturb sleep when they are unfamiliar to a person. Or we can say that sleep disturbance depends on the frequency of unfamiliar sounds. Generally, a person can awake from light sleep by a sound which is 30 – 40 decibels above from the level which can be detected when he is conscious, awake, and attentive. While in deep sleep, the same disturbance needs sound level 50 -80 decibels above than the level normally detected by a person when he is awake, conscious, and attentive.

8.18 Effects on Performance

Impact of noise on mental or motor tasks performed by a person are difficult to assess due to complexity of human behavior. Nonetheless, scientific studies have reached the following general conclusions. Steady noise without any special meaning seems to interfere with human performance

only when above 90 dBA. Irregular bursts of noise are more disruptive even when they are below 90 dBA. High frequency components of noise (1000 – 2000 Hz) may produce more interference with performance than low frequency components of noise. Noise is more likely to reduce accuracy of work than overall quantity of work. Complex tasks are more likely to be adversely affected by noise than simple tasks.

The permissible ambient noise levels with minimum impact on human health are shown in Figure 11.

Zone	Day-time	Night-time
Silent Zone	50	40
Residential Zone	55	45
Commercial Zone	65	55
Industrial Zone	70	70

Figure 11. Permissible ambient noise levels in India. (Ref. 6, [9])

Noise control measures

The ambient environmental noise could be reduced by alteration and modification at the level of source or path of noise transmission or receiver. By designing low noise machines and appliances or by some repair and modification of old equipment or machines we can minimize noise at source level. If modification at the source of noise is not possible then we can inhibit transmission of noise to the receiver. If both of the above approaches fail then at least we can protect the receiver.

8.19 Control of Noise Source

Designing noise free appliances and machines is part of mechanical engineering. Here, we would discuss general science by which we can create low noise equipment or may modify old one for reduction in noise. Following points could be considered for minimizing undesired sound level of a noise source.

Reduction of impact force

One of the causes of noise generation in a machine is collision between its components. Sometimes it could be required for the functioning of a machine such as contact of the platform of hydraulic lift with its load. We can reduce the noise generated from impact of two components by decreasing the force of collision between the objects. If it is not possible some cushioning support could be provided below the colliding surfaces or by replacing one impact head with nonmetallic material also reduces the resonance of the heads. A smooth acceleration of moving parts which avoid jerks also helps in reduction of noise.

Reduction of speeds and pressures

By reducing the speed of rotating and moving part of a machine and mechanical system we can reduce its noise output since speed reduction results in smoother operation. The speed of fans, impellers, rotors, and turbines could be reduced by increasing blade diameter which does not have any effect on job need. Similarly, reduction of flow speed of air, gas, and liquid in fluid circulation systems results in decreased noise radiation due to decline of turbulent flow. For example, a fifty percent reduction of the speed of air flow in an air ventilation system decreases its noise output by 10 to 20 dB or approximately one-quarter to one-half of original loudness.

Reduction of frictional resistance

Reducing friction between moving, rotating, and sliding makes the operation of the machine smooth and reduces its noise output. Following factors may be considered in reduction of noise in a mechanical system.

1. Alignment: Proper alignment of moving, rotating, or contacting parts reduces noise output. For example, good axial and directional alignment of shaft coupling, gear train, pulley system, and bearing and journal alignment are essential requirements for low noise output.

2. Balance: Balancing of rotating parts (both static and dynamic) of old machines reduces frictional resistance and vibration resulting in decline of machinery noise.

3. Polish: Highly polished and smooth surfaces of sliding, meshing and contacting parts (e.g. gears, cams, bearings, guides etc.) are needed for quiet operation. Lubrication further helps in reducing frictional resistance.

Isolation and damping of vibrating elements

In most of the mechanical systems except the simplest machine, vibration transfers from the vibrating component to other parts of the system creating overall vibration at much higher intensity than the source component of the machine. We can solve the noise problem by the two approaches: (1) isolation of the vibrating component from other parts of the machine, (2) dissipation of vibration energy by applying damping material on the vibrating surface.

Most effective way of isolating the vibrating component from other parts of the machine is its resilient mounting on the most massive and structurally rigid part of the machine. The connection of all other components to this part of the machine such as pipes, conduits, and shaft should be made with flexible or resilient couplers. For example, pipe connection to a pump (resiliently mounted on a massive spring mounted chassis of a machine) could be made with flexible tubing (installed closure to pump). The support of the pipe should also be made from a resilient material to avoid bypass of noise (Fig 12). Further reduction of noise (in our current example), could be made by applying damping material to the most vibrating surface. Damping materials have viscous properties due to which they convert vibration energy of the vibrating surface to internal movement of molecules (of damping material).

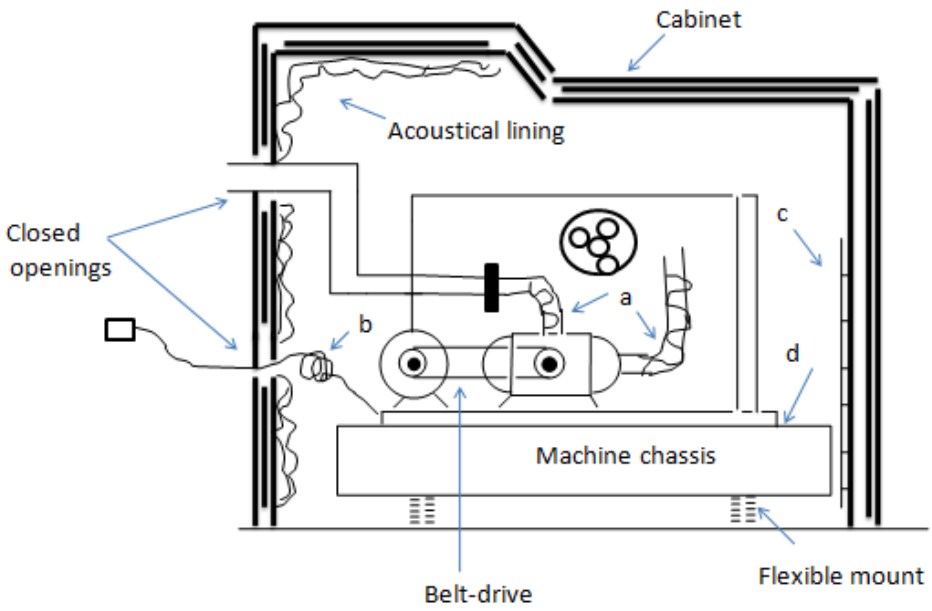


Figure 12. Noise reduction (in pump) by damping and vibration isolation. Here, a: flexible hose, b: flexible wiring, c: vibration damping material applied to most vibrating surface, d: motor, pump and fan installed on the most massive part of the machine. (Ref. 8)

8.20 Noise Control in the Transmission Path

After trying all possible ways to control noise at the source, the next line of defense is use of a device which can block transmission of noise towards the receiver. We can do this in several ways: (1) by absorbing the sound along the path, (2) by reflecting the sound in some other direction by placing a reflective barrier in its path. Depending on the size and type of source, intensity and frequency range of noise, and nature and type of environment we can select different most effective techniques. Few are mentioned below.

Separation

The divergence of sound in air as well as absorptive capacity of air could be utilized as an economical method for reduction of noise level. Each doubling of distance from a point source of noise reduces the sound level by 6 dB. However, the reduction is only 3 dB for each doubling of distance from line source of pollution such as running trains. The main reason for less attenuation of sound waves from line source is that sound waves radiated in the form of cylindrical shape. The surface area of cylindrical shape sound waves only increases twofold for each doubling of distance from the line source while in case of spherical waves (emitted by point source) it increases by four fold for each doubling.

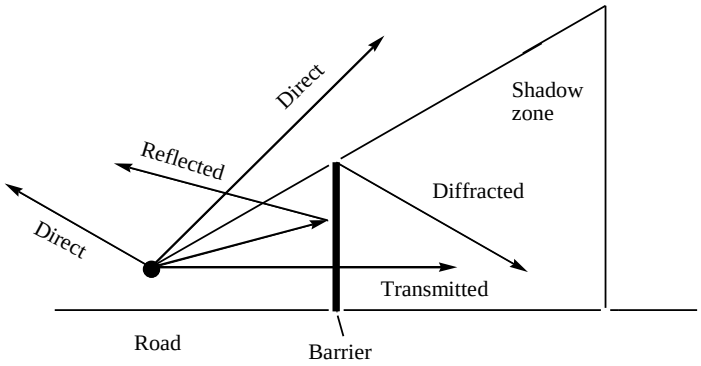
A decrease of 10 dB is needed for reduction of loudness of sound by half. For indoor environments, reduction of noise does not happen as much as for outdoor environments discussed above. This is because reflections of sound from off the hard walls and ceiling surfaces.

Barrier and panels

The placement of a barrier, screen, or deflector is another way of reducing noise on its transmission path. The height, length, and thickness of the barrier depend on frequency distribution of noise, attenuation needed and type of noise source (point or line source).

As shown in Figure 13, noise cam follows four different paths. It can follow a direct path without any attenuation. It could be reflected back from the barrier. It could be diffracted from the edge of the barrier. It could be transmitted from the barrier. The height of the barrier should be planned in a way that the receiver is not in line of sight of the noise source.

Two components of noise which could reach the receiver are diffracted and transmitted noise. The amount of diffracted noise could be reduced by increasing the angle of diffraction, while the transmitted noise could be reduced by increasing the thickness of the barrier. The noise barriers are being used to reduce traffic noise in many countries.



(A)

(B)

Figure 13. (A) Noise path from source to receiver (Ref. 8), (B) Actual noise barrier to reduce traffic noise.

8.21 Protect the Receiver

When both of the above approaches fail then protection of the receiver is the only option. It could be done by following two ways.

Alter work schedule

If the task in hand (e.g. construction and industrial operation), require working in a high noisy environment then instead working continuously for eight hours, the work could be finished in short interval of times in several days. Intensely noisily operations should not be performed at night (between 10 pm to 7 am) since the same noise level feels 10 dBA higher than measured value during sleep time.

Ear protection

Molded pliable ear plugs, cup type protectors and over the earmuffs could be used as hearing protectors. These devices can provide noise reduction from 15 to 35 dB. Maximum protection can be obtained when both muffs and earplugs are used.

While earplugs and muffs are devices to save our ear from high noise level, earphones (e.g., of digital music player) are ear-destructive devices. The "reverse" earmuffs direct the noise at the ear bypassing the protection mechanism of our outer ear. If you can hear sound or music coming from someone else's earphone, then that person is subjecting himself or herself to a noise level of 90-95 dBA.

You also download any sound meter app in your smartphone which give to idea of ambient noise level. The software of the app uses the microphone of the smartphone for estimating the ambient noise level in dB.

Soil pollution and its causes

As discussed in unit 1, soil is the foundation of all terrestrial ecosystems. It also helps in purifying and recharging underground water. Like water and air, soil is also suffering from pollution. Soil pollution is defined as any change in physical, chemical and biological properties of soil by natural or anthropogenic activity. Mostly soil pollution occurs due to chemicals and substances (termed soil pollutants) which are present in soil at higher-than-normal concentration that has adverse effects on non-target organisms.

Three important causes of soil pollution are: (1) accumulation of salts or salinization, (2) use of biocides, (3) excess use of fertilizers and acid rain.

Excess salts or salinization

Salinization of soil is a serious problem mostly in semi-arid and arid regions. The excess use of water in semi-arid regions often results in waterlogging due to low depth of soil in these regions. Water logging leads to movement of soluble salts accumulated in the depth of soil to move to the upper layers (topsoil including root zone) through capillary action. Further, due to high temperature in semi-arid regions water at top soil evaporates at faster rate leaving behind the dissolved salt back in the soil thus increasing salinity of soil.

High concentration of salt in soil water leads to osmosis driven desiccation of plant roots and subsequent death and consequent decline of soil fertility.

Biocides

Biocides such as fungicides, pesticides, rodenticides, and herbicides often enhance the crop production. Biocides, especially persistent organic chemicals, are often associated with biomagnifications killing keystone species and affecting population dynamics of many species including the resurgence of pests. Excess use of biocides, especially acutely toxic biocides (e.g. organophosphates and carbamates) also kills species of soil community which are essential for soil fertility through their involvement in nutrient cycling and maintenance of soil texture. For example,

copper-based fungicide used to control vine fungal diseases have a severe impact on earthworm and microbial biomass.[10]

Excess use of fertilizers and acid rain

Excess use of fertilizers especially nitrogen fertilizers in reduced form i.e. in the form of NH_4^+ ions results in acidification of soil. Excess ammonium ions get oxidized by *nitrosomonas* bacteria in soil to nitrite ions (Eq. 6).

$$2NH_4^+ + 3O_2 + 2H_2O \xrightarrow{Nitrosomonas} 2NO_2^- + 4H_3O^+ \quad (6)$$

As shown in Eq. 6, microbial oxidation of ammonium ions generates just double moles of hydronium ions contributing to a huge increase of acidity. Nitrite ions are further converted to nitrate ions but this does not add to soil acidity. However, since nitrate ion (NO_3^-) is negatively charged species it is not retained by negatively charged soil particles which have previously retained ammonium ions. Free nitrate ions now easily move to groundwater contaminate it.

Acid rain (discussed in unit 8) also adds hydronium ions (H_3O^+) to the soil increasing its acidity. Increase of acidity of soil decreases soil's nutrient holding capacity and mobilize toxic heavy metals in soil water. The negatively charged soil particles (clay and humus) hold positively charged ions such as Ca^{2+}, Mg^{2+}, K^+ which are needed by plants as nutrients. Excess addition of positively charged hydronium ions (through above mentioned processes) displaces above nutrients from negatively charged soil particles which got leached with downward moving percolating water. Hydronium ions also release toxic heavy metal (mostly added from landfill and industrial sites) which was strongly held by negatively charged soil particles (the cause of soil's ability to purify groundwater) such as anions of humic acids found in humus. The H_3O^+ ions also convert heavy metals present as insoluble minerals into soluble metal ions such as dissolution of insoluble aluminum hydroxide as soluble Al^{3+} species (Eq. 7). The released heavy metals which are toxic to plants eventually led to their death. Hence, processes which increase acidity of soil are significant cause of soil pollution.

$$Al(OH)_3 + 3H_3O^+ \longrightarrow Al^{3+}(aq) + 6H_2O \quad (7)$$

Use of nuclear energy

Nuclear energy has both destructive and constructive use. As constructive we use it in carbon free electricity generation, in medicine it is used in cancer radiotherapy and in the form of different radioactive isotopes it is used as tracer-based imaging for diagnosis of many diseases. Radioactive isotopes are also used for metabolic study of investigational drugs and for dating of ancient objects. The widely used X-rays for scanning of the human body and other objects are also one of the major radiations emitted by radioisotopes.

Nuclear energy also has a lot of destructive power in the form of nuclear warfare. Nuclear capable missiles could use atomic and hydrogen bombs and pose a danger for humanity if they are used in war between nations. The destructive use of nuclear energy also makes us aware about potential hazards associated with nuclear energy. However, the most important use of nuclear energy is for power generation. Before understanding the type of nuclear hazards associated with nuclear power plants let us first learn the functioning of a common fission based nuclear power plant.

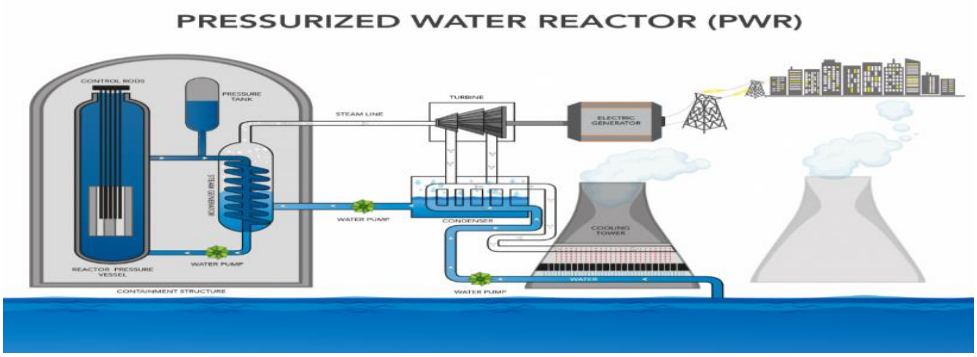


Figure 14. Functioning of a nuclear power plant. (Source: US DOE)

The most important component in conversion of nuclear energy to electrical energy is nuclear core or nuclear reactor where fuel rods containing sufficient amounts of fissionable nuclei (mostly U-235) are surrounded with control roads (Fig. 14). When the core becomes critical it has sufficient neutrons to start a controlled chain reaction. In the chain reaction heavier U-235 is broken down to daughter nuclei such as Ba-144 and K-89 releasing vast amount of energy obtained from loss mass in fission reaction (mass and energy are related to each other through $E = mc^2$, m is loss of mass and c is velocity of light). Though nuclear energy provides us carbon free energy, the problem occurs in formation of daughter nuclei which are not just limited to Ba-144 and Kr-89, but many different atomic nuclei are generated during fission. The relative abundances of these nuclei generated in fission of U-235 are shown in Figure 15. Majority of these isotopes are unstable radioisotopes which generate harmful radiation during their decay to stable nuclei.

To contain the radioactive nuclei during generation of nuclear energy, water used to absorb heat generated in the nuclear core is not allowed to be converted into steam, but it flows in a primary loop at high pressure. The super heated water circulates through a heat exchanger to convert water flowing in the second loop into steam which runs a steam turbine coupled to an electric generator (Fig. 14). The spent steam is cooled in a cooling tower coupled condenser.

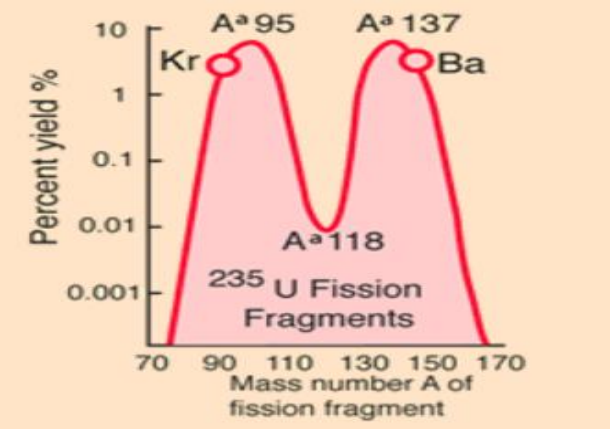


Figure 15. Abundance of different nuclei formed in fission of U-235.

After consumption of fissile nuclei in fuel rods chain reaction gets stopped and spent fuel rods are replaced with fresh fuel. However, spent fuel still contains a lot of radioactive mass composed of different radioactive fission products, which pose different biological hazards. Let us learn about them.

Nuclear hazards and human health risk

The radioactivity of a radioisotope is measured in unit 'curies'. One curie is radiation emitted by one gram of pure radium-226 per second. It is equal to approximately 37 billion disintegrations per second. The radioactive decay of an unstable element generates four different ionizing radiations as shown in Figure 16.

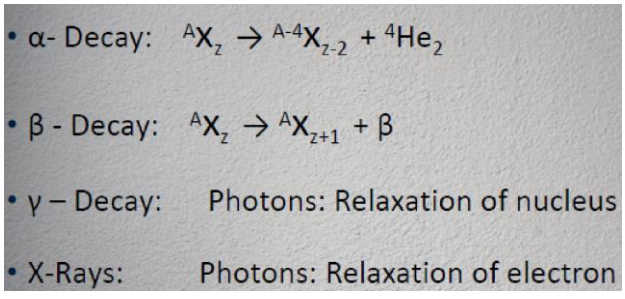


Figure 16. Four ionizing radiations generated from radioactive decay.

α-Decay generates a helium nucleus and the parent nucleus gets converted to daughter nucleus of mass which is 4 a.m.u. (atomic mass unit) less than parent nucleus and its atomic number is 2 less than the parent nucleus. β-Decay generates an electron and daughter nucleus with the same mass number but an increase of atomic number by one unit. γ-Decay generated from energetic radioisotopes with its nucleus in a higher energy state. The energetic nucleus of a radioactive element

gets relaxed to a ground state liberating a photon (called γ-photons) instead of a particle. The daughter nucleus which forms after α- or β- decay are generally in excited nuclear state which relaxes back to ground state by emitting the γ-photons. X-Ray photons are generated with energetic atoms with inner shell electrons in excited state during relaxation of the element back to ground state.

The biological effect of ionizing radiation is measured in terms of radiation energy absorbed per unit mass of body tissues (called radiation dose D) which is measured in unit J/kg. However, the impact of different radiation is not the same for the same amount of energy deposited by them to body tissues. For example, α-particles would cause more damage to body tissues than γ-photons of the same energy since energy loss per unit length (termed linear energy transfer or LET) is higher for α-particles than γ-photons. The difference of biological impact of different radiation is incorporated in a new parameter called equivalent dose denoted by symbol H. The unit of equivalent dose is sieverts (Sv). H is defined as:

$$H = w.D \quad (7)$$

where w is the weighting factor for a given radiation.

Value of w for X-rays, γ-rays and electrons is one, while for neutrons and α-particles its value reaches 20. Nuclear radiations are ionizing radiations which ionizes bio-molecules of exposed tissues resulting in formation of radical ions. These radical ions break down to smaller fragments or rearrange to very different structures damaging the functioning of cells of affected tissue.

The effect of radiation exposure depends on the amount of equivalent dose. An exposure of radiation of more than 1 Sv is called high dose exposure, while an exposure that ranges between 100-500 mSv is termed low dose exposure. High dose exposure results in an acute effect called radiation sickness. Low dose creates delayed effects such as malignant tumors and birth defects.

High doses of exposure cause enough damage in tissues to stop cell division. The focused high doses are used to kill cancer cells in radiotherapy. However, if the whole body got exposed to high doses then it leads to generalized blockage of cell division stopping the generation and repair of blood, skin and other tissues (termed radiation sickness). A person exposed to high doses of radiation generally suffers death within a few weeks or in a month.

Low dose of radiation only causes mutation in DNA, but does not have any acute effect. The DNA mutations in somatic cells (cells except germ cells) may lead to malignant tumors especially leukemia. Mutations in DNA of germ cells (sperms or egg cells) lead to birth defects in off-springs. Often the impact on human health of low dose radiation is visible after 10 to 40 years of exposure incidence. Other health effects of low dose radiation are weakening of immune system, mental retardation (e.g. Down syndrome which is often caused by prenatal exposure of mothers) and development of cataract.

The greatest nuclear hazards are associated with accidents in nuclear power plants (see the case study below) and nuclear warfare. Nuclear accident unintentionally releases harmful radioisotopes and radiations, but nuclear warfare is deliberate release of radioisotopes in addition devastating energy (in form of heat and shock wave).

Fukushima nuclear accident

Earthquakes are common for Japan, which is situated over Pacific Rim, a region of high seismic activity. On March 11, 2011 Japan suffered an earthquake of magnitude nine which was triggered by sudden subsidence of Pacific tectonic plate under Okhotsk plate (part of Northern Japan). An up-thrust of the ocean covered floor of the Okhotsk plate by 5-8 meter triggered a 40 m high tsunami which hit the northern coast of Japan at Fukushima prefecture (state) and crossed the seawalls meant to protect the cities. Tsunami waves swamped the city pushing debris, vehicles, and buildings inland at frightening speed. The tsunami caused deaths of 20,000 as people found little time to escape the incoming waves.

At the time, 30% of Japan's power demand was fulfilled by nuclear power plants. Most of these power plants were situated at the coastal line where cooling water was available easily. After the magnitude nine earthquakes, eleven nuclear power plants were automatically shut down including six of the Fukushima Daiichi Nuclear Power Plant. Since the earthquake cut the plant's electrical supply, emergency generators started to supply cooling water for dispelling radiation heat in shutdown reactors. However, after 50 min a 40 m high tsunami swamped the plant, and the water entered the fuel tank of emergency generators stopping the pumps' supply of cooling water in the reactor's core. Overheating of the reactor core resulted in leakage of steam and hydrogen (generated from

thermolysis of water) from the core of reactor 1, 2, 3 and 4 of the plant. The steam and hydrogen accumulated in the upper portion of the containment building and triggered the explosion of reactor 1, 3 and 4, while gas in reactor 2 vented off (Fig. 17).

Radioactive fallout converted an area under 20 km radius from the plant into a dead zone causing evacuation of 75,000 people. Some 800 workers worked in short shifts (to minimize the radiation exposure) to bring reactors under control. Continuous pumping of seawater led to a cold shutdown of the reactor at the end of 2011. The disposal of contaminated seawater stored in more than 1000 tanks, recovery of fuel from intact and melted fuel rods and dismantlement of the nuclear reactor will take another 30 years and need a budget of US$ 76 billion while construction of the plant just required US$ 2.2 billion. Though no radiation related illness was reported, residents suffered from displacement induced social and psychological stress.[11]

Figure 17. The damaged reactor units of Fukushima Daiichi Nuclear Power Plant. (Source: The New York Times)

Summary

Water flows in cycles whether it is a hydrological cycle or its sub-cycles: surface runoff and groundwater loops. We extract the water from surface and groundwater resources. After being used for the intended purpose, the water returns back as wastewater to natural water bodies, especially rivers or streams. During consumption of water for various human activities, a lot of pollutants are added in water. The major categories of water pollutants are pathogens, oxygen demanding waste, heavy metals and salts, nutrients, pesticides including new and emergent pollutants. Pathogens are responsible for many waterborne disease outbreaks. Discharge of excess oxygen demand in natural water bodies not only asphyxiates aquatic animals and plants but also makes the water toxic due to additional toxic end products of anaerobic degradation of organic waste. Nutrients due to their accumulation in still water bodies such as lakes also disturb the population dynamics of a lake ecosystem by boosting algal growth. The algal bloom (eutrophication) also asphyxiates aquatic species in the hypolimnion (cold) zone of the lake. Many heavy metals and organic chemicals (DDT, perfluoroalkyl carboxylate, algal toxins etc.) though present in water at concentration not harmful for living species got accumulated in food chain (the phenomenon called biomagnifications) and affects species situated at higher trophic level including humans. It is important that all man-made pollutants entering the water during its use should be removed before discharge of water back to natural water bodies. Due to the movement of water in cycles there are chances that the same pollutant can find its way in our drinking water and food. Noise present in our atmosphere is another pollutant which affects our well-being. Sound pressure level of noise which is measured in decibel (dB) is an important parameter in assessing impact of noise on humans. Exposure of high noise level (above 90 dBA, here A in dBA is noise rating system) for a day can lead to temporary threshold shift and if a person continues to be exposed with high noise level then it leads to permanent threshold shift. Judging a sound noise depends on individual human reaction (that is why we have three rating systems A, B and C) and low-level noise can cause many psychological problems in affected persons such as sleep interference, annoyance and resultant cardiovascular diseases, poor performance etc. By creating low noise devices or by stopping noise in its path we can minimize the impact of noise. In addition to pollution of natural water resources and the atmosphere, our soil is also getting polluted. Soil pollution is caused by chemicals and substances which present in soil in higher-than-

.

normal concentrations which harm non-target species and reduce the fertility of soil. Accumulation of salt, excess use of biocides and acidification of soil by excess use of nitrogen fertilizers and acid rain are the major causes of soil pollution. Nuclear energy though useful for providing carbon free electricity and helpful in medical imaging and treatment have also been associated with many hazards. These hazards are linked to ionizing radiation emitted from radioisotopes either used in pure form or being part of radioactive waste. Impact of radiation on human health depends on radiation dose which is measured in units of sieverts. Exposure of radiation more than 1 Sv (seiverts) leads to radiation sickness while low dose of radiation (between 100 -500 mSv) may cause cancer and birth defects in exposed persons.

Self Assessment

1. Industrial wastewater discharged in a river is _____ source water pollution.

A. Nonpoint
B. Point
C. Line
D. Double point

2. _____ reduces dissolved oxygen (DO) of the water body.

A. Nutrients
B. Pathogens
C. Salts
D. Oxygen demanding waste

3. Eutrophication of a water body (lake or pond) is characterized by _____

A. Algal bloom
B. Decline of dissolved oxygen
C. Increase of water quality
D. Both algal bloom and decline of dissolved oxygen

4. Pathogens are major water pollutants which are responsible for _____

A. Decline of dissolved oxygen of water bodies
B. Spread of waterborne diseases
C. Increase of salinity of water
D. Increase of temperature of water

5. Accumulation of persistent organic chemicals such as DDT in food chain is known as _____

A. Eutrophication
B. Algal boom
C. Hibernation
D. Biomagnification

6. Secondary treatment of domestic wastewater involves use of _____ to reduce BOD of wastewater.

A. Sedimentation
B. Aerobic microbial process
C. Anaerobic microbial process
D. Screening

7. _____ is the unit of sound level.

A. Hertz
B. Meter
C. Second

D. Decibel (dB)

8. _____ is the unit of sound frequency.

A. Hertz
B. Meter
C. Second
D. Decibel (dB)

9. _____ dB is the minimum sound level that ears of a healthy young person can recognize.

A. 20
B. 30
C. 100
D. 0

10. If you experience a 90 dB sound for more than 8 hours, then it can cause _____

A. Diarrhea
B. Hearing impairment
C. Asthma
D. Burn injury

11. By designing machines with very low mechanical vibration we can control noise at _____ level.

A. Path
B. Receiver
C. Source
D. Non source

12. Biocides causes soil pollution by _____

A. Increasing soil erosion
B. Killing soil biota
C. Increasing salinity
D. Decreasing soil porosity

13. Majority of nuclear power plants are based on _____

A. Fusion H- nuclei
B. Fission of U-235
C. Fission of U-238
D. Combustion of coal

14. Main issue associated with use of nuclear energy is _____

A. Generation CO_2
B. Disposal fly ash
C. Disposal of radioactive waste in spent fuel
D. Generation of air pollutants

15. α-Decay of radioactive elements releases helium nucleus, while β- decay of radioactive elements releases _____

A. γ- Photons
B. X- Ray photons
C. Electrons

D. Protons

16. Biological effects of radioactive exposure is measured in unit of _____

A. Curie
B. Sievert (Sv)
C. Kilogram
D. Meter

Answer for Self Assessment

1.	B	2.	D	3.	D	4.	B	5.	D
6.	B	7.	D	8.	A	9.	D	10.	B
11.	C	12.	B	13.	B	14.	C	15.	C
16.	B	.							

Review questions

1. How do we estimate oxygen demanding waste present in water? Explain impact of oxygen demanding waste on rivers.
2. What are emerging water contaminants? Explain their impact on human health.
3. How do nutrients affect the Lake Ecosystem?
4. What is biomagnification? What are conditions which increase the potential of a substance to bio-accumulate? Give a few examples.
5. Explain treatment of domestic wastewater to remove major water pollutants with diagrams.
6. What is noise? Explain important parameters which characterize a noise.
7. Explain the major physiological impact of noise on humans.
8. How does noise interfere with normal conversation?
9. What are the various psychological impacts of noise? Explain.
10. How can we control noise at source level?
11. Explain control of noise in its transmission path.
12. What are the major reasons for soil pollution?
13. What are the hazards associated with nuclear power generation?
14. What do you mean with high and low dose radiation exposure? How do these radiation doses affect human health?

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Unit 09: Climate Change

Objectives
Introduction
9.1 Global warming
9.2 Carbon dioxide: Principal green house gas
9.3 Impact of global warming on oceans
9.4 Global warming and adverse weather events (climate change)
9.5 Mitigation strategies for climate change
9.6 UV radiation
9.7 Ozone layer: Protective shield
9.8 Antarctic ozone hole
9.9 Impact of UV Radiation on Human Health
9.10 Acid rain and its formation
9.11 Impact of acid rain on terrestrial ecosystems and materials
9.12 Impact of Acid Rain on Aquatic Ecosystems
Summary
Key words
Self Assessment
Answers for Self Assessment
Review Questions
Further Reading

Objectives

After completion of this chapter you will be able to

- know factors on which average global temperature depends.
- know how carbon dioxide is a principal greenhouse gas.
- understand how rise in average global temperature is responsible for adverse weather events.
- know how ozone layer in stratosphere protects us from harmful UV radiations.
- know why ozone hole formed only over Antarctica.
- understand impact of increased exposure to UV on health.
- know what is acid rain.
- understand impact of acid rain on aquatic and terrestrial ecosystems.
- understand impact of acid rain on materials.

Introduction

Mumbai and Konkan region (northern portion of Western Ghats) of India suffered from flood in recent monsoon (July, 2021). The southern portion of Western Ghats (part of Indian state Kerala) also suffered from two continuous floods during the monsoon season in the years 2018 and 2019. The historic heat wave condition (June, 2021) in Pacific Northwest (comprising many cities of US and Canada), led to sharp increase of hospital visit for heat related illnesses and prodded some people to buy air-conditioner for first time. Recent (July, 2021) huge forest fire at southern and western coast

in Turkey which spread to areas four times higher than the average area (between the years 2008 to 2020) has converted a coastal paradise of pine and olive forest to ashes. Similarly a year before (Sep, 2020) forest fire in western US states of Oregon and California turned the sky of San Francisco orange leading to longest 'spare the air alert' in the city.

The cause of all of the above and many other adverse weather events (such as more frequent and destructive tropical storms) is traced to change in climate of Earth caused by rise in average global temperature. In this unit we would discuss how just a few degree Celsius rise in average global temperature can cause a destructive adverse weather event. We would also discuss the causes and mitigation strategies of climate change. In addition to climate change two other man-made problems acid rain and ozone layer depletion are also affecting human welfare. This unit would also discuss the impacts and causative reasons of acid rain and ozone layer depletion.

9.1 Global warming

Temperature and precipitation are two important parameters deciding climate (long term weather pattern) of a region. However, precipitation is also dependent on average global temperature as it affects coupled ocean atmosphere circulations (vide infra). In last 800,000 years history of Earth, there occurred eight ice ages and eight interglacial periods. The reasons behind periodical climate change in the history of evolution of Earth are: cyclical changes in eccentricity of Earth's orbit (changes from elliptical to circular orbit in a period of 100,000 years), obliquity of Earth axis (changes of obliquity of Earth axis from 21.5° to 24.5° in a period of 41,000 years, the current obliquity is at 23.5°), and precession of Earth axis with a period 23,000 years. However, above natural changes in Earth climate is associated with the long term variation of Earth's orbit. The currently observed change in our Earth's climate is due to man-made global warming (Fig. 1) instead of changes in solar radiation caused by change in Earth's orbit.

To understand causes responsible for global warming, let's first learn about factors which determine Earth's average temperature. The temperature of Earth depends on amount of solar energy coming towards Earth from sun and amount of energy radiated back by the Earth to space. Since there is equilibrium between energy absorbed and emitted energy by Earth, we can estimate (as first approximation) Earth's temperature calculating the amount of energy radiated and absorbed considering Earth as a black body.

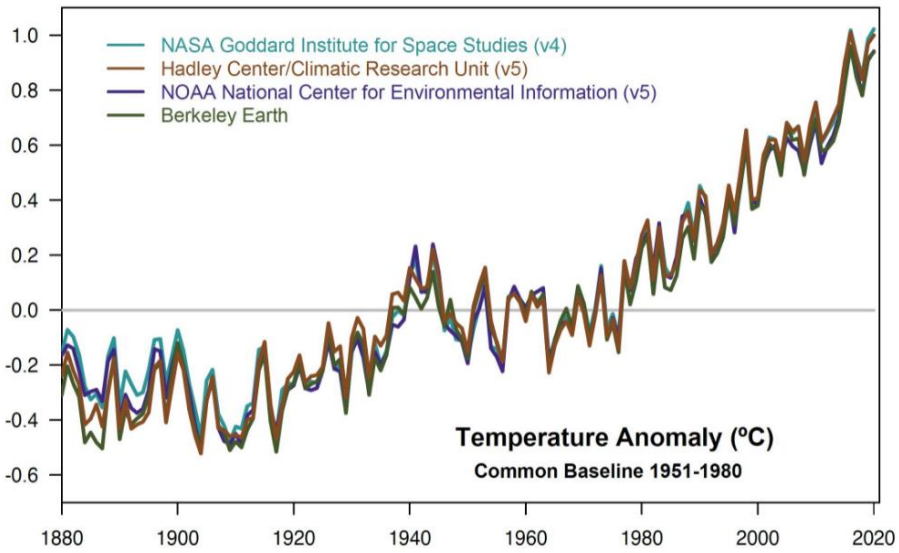


Figure 01: Rise of average global temperature depicted as temperature anomaly (difference between average temperature in particular year and baseline temperature). The baseline temperature (14°C) is the average temperature in the period of 1951-1980. (Source: GISS, NASA)

The energy absorbed by the Earth could be found out by use of *solar constant*, *S* and *albedo*, α of Earth. Solar constant is amount of solar energy per unit area coming from sun to Earth when sun is directly above the surface of Earth. This energy is measured without interference of atmosphere i.e. outside the Earth's atmosphere. Its value is around 1,370 W/m^2. Albedo of a planet is fraction of solar energy reflected by a planet. For Earth, mean value of albedo is estimated to about 31%.

We can use solar constant to calculate amount of solar energy received by the Earth (Fig. 2). The total energy striking to Earth is equal to solar radiation passing through the hypothetical circle of same radius as of Earth.

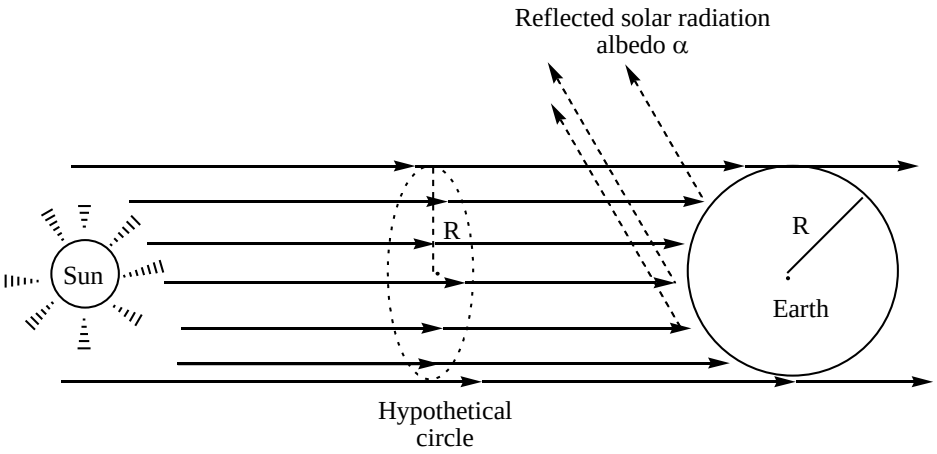


Figure 02: Solar radiation passing through hypothetical circle of same radius as Earth is the energy which can be received by Earth (Ref. 1).

So, we can write

$$\text{Energy received by Earth (per second)} = \pi R^2 S \quad (1)$$

Not all of this energy is absorbed by Earth, as some is reflected back to space by clouds and ice sheets present on Earth. So,

$$\text{Energy reflected by Earth (per second)} = \alpha\pi R^2 S \quad (2)$$

Therefore,

$$\text{Energy absorbed by Earth} = (\pi R^2 S) - (\alpha\pi R^2 S) = (1-\alpha)\,\pi R^2 S \quad (3)$$

Now we need to calculate the energy which is radiated back to space by Earth. For this we can assume Earth as black body (a substance which can absorb of energy incident on it and can emit all the absorbed energy) and we also assume it isothermal that is temperature is same everywhere on Earth. Now we can use Stefan-Boltzmann Law of Black-Body radiation. The energy radiated per second by a black body is proportional to its surface area and to the forth power of its absolute temperature. Since Earth is almost spherical, so we can write

$$\text{Energy radiated by Earth (per second)} = \sigma 4\pi R^2 T_e^4 \quad (4)$$

where

σ = Stefan-Boltzmann constant = 5.67×10^{-8} W/m^2. K^4

T_e = Earth's "effective" black body temperature

There is equilibrium between energy absorbed and radiated back by Earth, so we can equate Equations 3 and 4. Or

$$(1-\alpha)\,\pi R^2 S = \sigma 4\pi R^2 T_e^4 \quad (5)$$

Solving for T_e,

$$T_e = \left[\frac{S(1-\alpha)}{4\sigma}\right]^{1/4} \quad (6)$$

Substituting values for constants into Eq. 6 yields

$$T_e = \left[\frac{(1370\ W/m^2(1-0.31)}{(4 \times 5.67 \times 10^{-8}\ W/m^2.K^4)}\right]^{1/4} = 254\ \text{K} = (254 - 273)^\circ\text{C} = -19^\circ\text{C} \quad (7)$$

Above simple model gives Earth temperature -19°C, but actual average global temperature of Earth is 15°C or 288 K. If our Earth had an average temperature of -19°C then survival of many species was not possible. Now what is the problem with the model we used for estimating Earth's temperature? In our current model we have ignored the impact of atmosphere. Next section is about role of atmosphere in deciding average temperature of Earth.

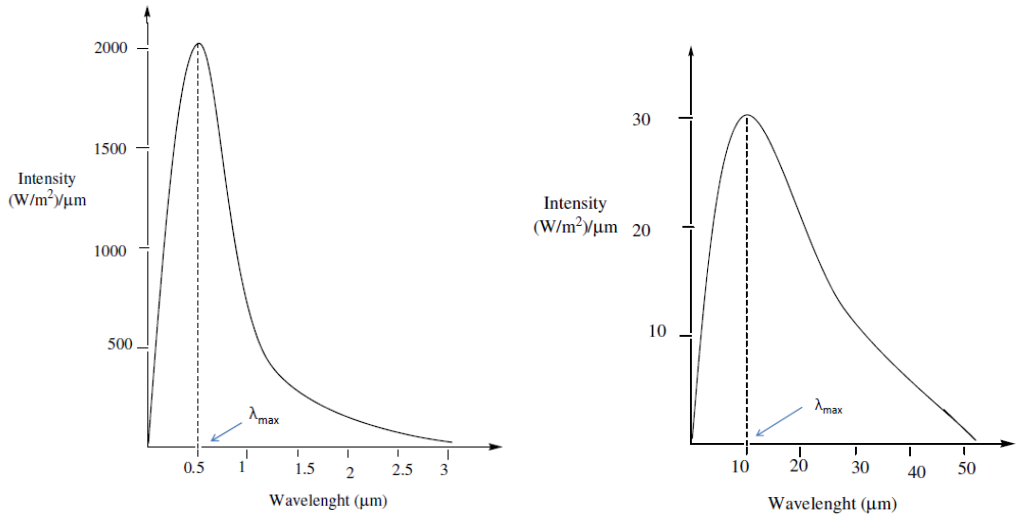
9.2 Carbon dioxide: Principal green house gas

Before understanding how average global temperature is affected by atmosphere, let us first understand distribution of energy of black body radiation at various wave lengths. The energy radiated by black body is not distributed equally at each wavelength, but the distribution shows λ_{max} (wavelength which contain highest amount of energy) value which depends on absolute temperature of black body.

The relationship between λ_{max} and absolute temperature is expressed by 'Wein displacement law'. As per the law value of λ_{max} of a black body radiation displaces to shorter wavelength as its absolute temperature (measured in K) increases. Or we can express λ_{max} as

$$\lambda_{max} \text{ (in } \mu m) = \frac{2898}{T} \quad (8)$$

The surface temperature of sun is 5800 K, so it emits most of its energy at wavelength 0.5 µm or 500 nm which is a wavelength of yellow light. Due to emission of most of the energy from sun in the form of yellow light; it looks yellow to us. The average surface temperature of Earth is 288 K, therefore it emits most of its energy centered at wavelength of 10.1 µm which is an infrared radiation (Fig. 3). So, sun emits in 'short wavelength region' while the Earth emits in 'long wavelength region'. Here comes the role of atmosphere.



(A) (B)

Figure 03: Blackbody radiation of: (A) Sun (surface temperature 5800 K), (B) Earth (surface temperature 288 K).

Our atmosphere composed of various gases which are almost transparent for short wavelength radiations coming from the sun, but it absorb infrared radiation (IR) emitted by Earth. Atmosphere contains many IR active gases (such as CO_2, H_2O, CH_4 etc.) which absorb IR radiation in the same wavelength zone as used by Earth to emit radiation back to space (Fig. 3B). The gaseous substances which absorb radiation above 4 µm are called green house gases (GHG). Only molecules which have permanent dipole moment (polar molecules such as H_2O) or which changes dipole moment during their vibration motion (IR excite vibration level of molecules) can only interact IR radiation. The non polar molecule like O_2 and N_2 does not interact with IR radiation and are termed IR inactive. Water vapor absorbs radiation with wavelength less than 8 µm and CO_2 shows a strong absorption band centered at 15 µm. Between 7 µm and 13 µm sky is mostly clear for outgoing thermal radiation.

The radiation absorbed by green house gases in atmosphere is emitted back towards surface of Earth and space (Fig. 4), thus atmosphere works as blanket and average global temperature (288 K) is higher than effective blackbody (T_e) of Earth i.e. 254 K (as calculated in previous section). The difference between actual surface temperature (T_s) and effective blackbody temperature of a planet (T_e) is called 'greenhouse effect' of atmosphere. For Earth magnitude of greenhouse effect is 34°C, while for Venus it is 521°C.

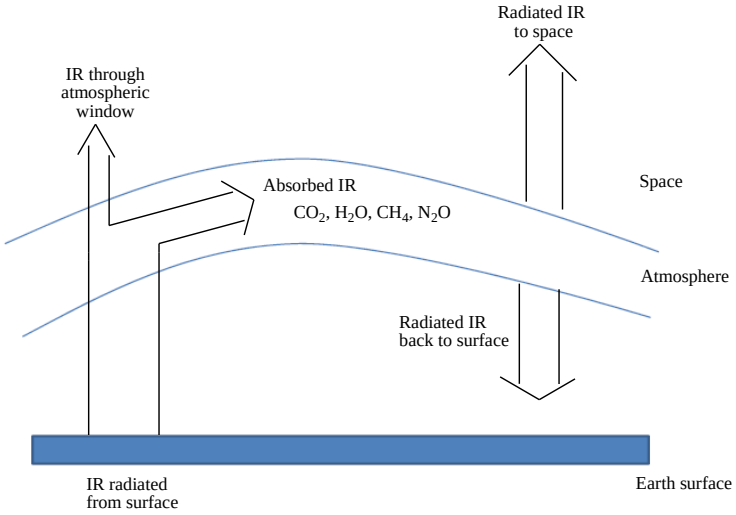


Figure 04: Greenhouse effect of atmosphere.

Human perturbation of carbon cycle

Currently, numbers of anthropogenic gases are enhancing greenhouse effects of atmosphere, leading us to future of uncertain global climate. The important greenhouse gases are: CO_2, CH_4, N_2O, and halocarbons (mostly used as refrigerant). Emission of black carbon and particulate matter (PM) also enhances the greenhouse effect. Though different gases have different '*Global Warming Potentials*' (GWP), which is a quantity that measures global warming efficiency of a given gas with respect to carbon dioxide in a given period. We can compare greenhouse effects of emissions of various chemicals by multiplying GWP of the substance with its emission rate. Of the all contributor of greenhouse effect, share of carbon dioxide is highest at around 80%.

Carbon dioxide is one of the major forms of carbon involved in biogeochemical cycling of carbon. However, human activities are disturbing this important biogeochemical cycle. Let us understand how we are modifying carbon cycle.

Around 800 GtC (giga ton of carbon) is stored in atmosphere, while some 610 GtC is locked in terrestrial vegetation. These amounts of carbon are dwarfed by content of carbon locked in oceans which is about 39,000 GtC. The exchange of carbon between atmosphere and biosphere (through processes of photosynthesis and respiration) is of the order of around 60 GtC/yr. Oceans absorbs some 90 GtC of carbon. Same amount of carbon is released back to atmosphere by oceans. Most of the absorbed carbon in oceans remained in the form of HCO_3^- and some of it becomes part of marine food chain. A small portion of organic carbon stored in detritus deposited each year as sediment. The accumulated sedimentary carbon over long geological period is converted to fossil fuel. Our use of fossil fuel is releasing the ancient carbon back to atmosphere.

In comparison to natural fluxes, human addition of carbon to atmosphere is much smaller, but enough to disturb the climate system. Figure 5 depicts human perturbation to the carbon fluxes into and out of atmosphere during the period of 1990s. During this period fossil fuel use and cement production added 6.3 GtC/yr to atmosphere, while change in land use (such as conversion of forest land to industrial zone which add additional carbon in atmosphere from burning of biomass and mineralization of humus) added 2.2 GtC to atmosphere.

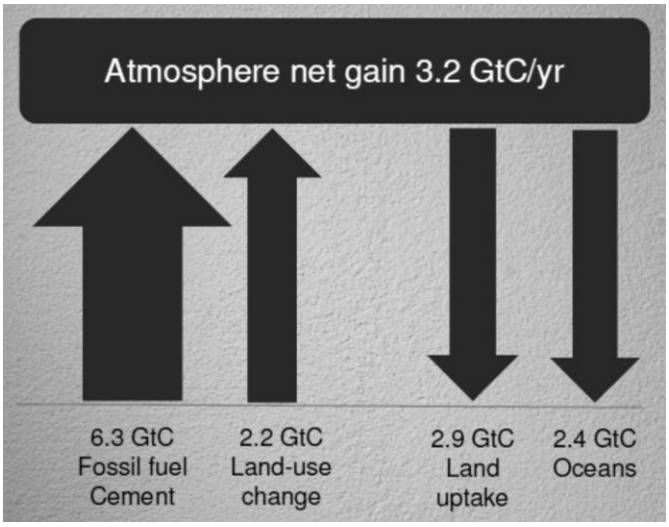


Figure 5: Human perturbation of global carbon cycle during 1990s. (Ref. 1)

As shown in the Figure 5, a total of around 8.5 GtC/yr extra carbon is added to atmosphere due to anthropogenic activities, but not all of that remain in atmosphere. The deliberate afforestation and stimulation of plant growth caused by high CO_2 level and fertilization of soil from nitrates coming from fossil fuel combustion, takes up an additional 2.9 GtC (approx.) carbon. High concentration of CO_2 in atmosphere also increases absorption of CO_2 by oceans which account for around 2.4 GtC additional uptake. Still after natural uptake of additional CO_2 there remains some 3.2 GtC (= 8.5 – 5.3) that persists in atmosphere. The fraction of anthropogenic carbon which remains in atmosphere to the carbon emitted by anthropogenic activities is called 'airborne fraction'. The airborne fraction in our current case is 38%. So, every year around 38% additional carbon is added in atmosphere. The cumulatively increasing carbon in the form of carbon dioxide in atmosphere (Fig. 6) is also leading to increase in absorption of outgoing IR radiation from the Earth surface which consequently forcing more radiation back to Earth.

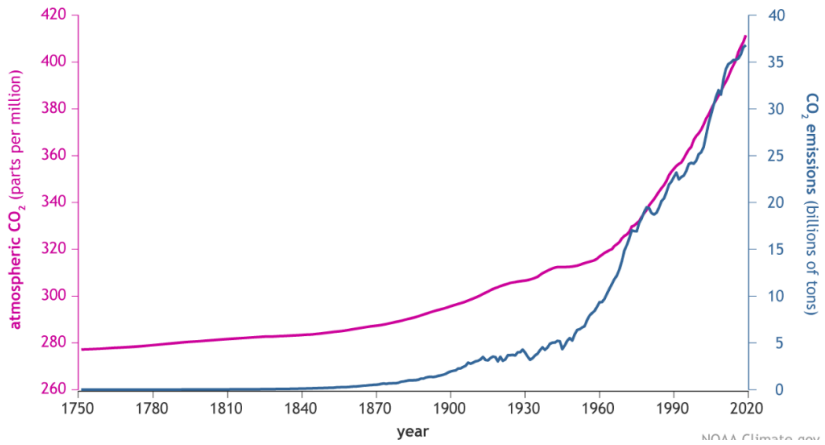


Figure 6: Rising emission of CO_2 and consequent rise in its atmospheric concentration from 1750 to 2020. (Source: NOAA, US)

The concentration of CO_2 before Industrial Revolution was 280 ppm, as inferred from Antarctic ice cores and other evidences. In 2019, it reached to value of 412 ppm, a 47% increase since the beginning of Industrial era.[2]

Radiative forcing of climate change

Earth absorbs around 235 W/m^2 of solar energy coming as short wavelength radiation and it radiate back the same amount of energy in the form of long wavelength radiation. So, the surface temperature of Earth remains constant. If the energy balance of Earth is disturbed by addition of extra radiation (called radiative forcing ΔQ) then it would also increase the equilibrium temperature (T_e) of Earth.

It has been established that doubling of concentration of CO_2 in atmosphere would add 4.2 W/m² more radiation towards the Earth's surface. Determination of radiative forcing associated with different greenhouse gases and other factors such changes in albedo and sun's radiation is one of the important aspects of modeling of future climate. The second most important question is what is the relationship between radiative forcing and rise of Earth's average equilibrium temperature? A convenient linear relationship is often used for predicting future average global temperature for given radiative forcing.

$$\Delta T_e = \lambda.\Delta Q \qquad (9)$$

The proportionality constant λ, called 'climate sensitivity factor' is very important parameter in General Circulation Model (GCM) used to predict response of climate system to increasing atmospheric concentration of greenhouse gases. The simple use of Stefan-Boltzmann Law which relates energy radiated by blackbody to its absolute temperature could be to calculate 'climate sensitivity factor' (λ). However, this provide λ value (called blackbody climate sensitivity λ_B) of 0.27 °C/(W/m²). The use of λ_B leads to just 1.1°C rise in equilibrium surface temperature, which is much smaller than the rise of surface temperature, predicted by majority of general circulation models.

The low value of λ, if we consider Earth as blackbody, is due to ignoring many complicating feedback factors which affects climate sensitivity. These factors are:

Ice-albedo feedback

Ice is highly reflective and in the form of vast ice sheets on Earth they have huge contribution in the albedo of the planet. The radiative forcing induced warming of Earth surface decreases the surface area of ice sheets. The declining ice sheets expose the darker surface of Earth and consequently albedo of Earth declines and more energy gets absorbed. The ice-albedo induces '*positive feedback*' in climate sensitivity and global warmimg.

Water-vapor feedback

The warming of Earth's surface by radiative forcing, add more water vapor in atmosphere. Water vapor is a strong greenhouse gas and it increases the greenhouse effect by trapping more outgoing radiation resulting in enhancement of radiative forcing. So, the water vapor creates a positive feedback loop.

Cloud feedbacks

Cloud especially fluffy white cloud can be highly reflective. The increase of water vapor in atmosphere leads to more cloud formation and consequently increases the albedo of the planet and lowers the surface temperature. This is an example of '*negative feedback*' of radiative forcing where the feedback reduces the original perturbation. But, in addition to be reflective cloud also absorbs thermal (IR) radiations which provide positive feedback in global warming. The modeling of cloud feedback is one of the most challenging tasks in climate science. The consensus seems to be that cloud yields overall positive feedback in increasing average global temperature.

Lapse rate feedback

Lapse rate is the rate of decline of temperature of atmosphere with altitude. If radiative forcing induced surface warming increases or decreases the original lapse rate then it has positive or negative feedback, respectively, on global warming.

One way to include contributions of feedbacks is by creating a summing device incorporating feedback loops with gain factor denoted as 'g'. Figure 7 illustrate the summing device.

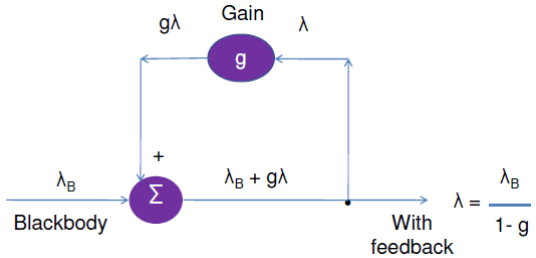


Figure 7: A simple model to estimate climate sensitivity λ from blackbody climate sensitivity λ_B by accounting for feedback phenomenon.

As explained in above model (Fig. 7), we can write:

$$\lambda = \lambda_B + g\,\lambda \quad (10)$$

Solving for λ gives

$$\lambda = \frac{\lambda_B}{1-g} \quad (11)$$

The gain 'g' can be expressed as sum of individual feedback factors

$$g = g_{\text{water vapor}} + g_{\text{cloud}} + g_{\text{surface ice}} + g_{\text{lapse rate}} + g_{\text{other}} \quad (12)$$

As is clear from Eq. 11, climate sensitivity λ becomes very sensitive to feedback factors as 'g' approaches to 1. If we know the gain factor 'g' and radiative forcing for a given amount of increase in a greenhouse gas we can estimate the future rise in average global temperature.

The control knob governing Earth's temperature

Since water vapor and clouds account for lion share (75%) of greenhouse effect, some skeptics argued that role CO_2 is not very significant, which is the main target of emission cut. However, water vapor is condensable gas which could easily be removed as the atmospheric temperature declines. It is the non-condensable greenhouse gases (GHG) which through radiative forcing induced positive feedback process; sustain the water vapor in atmosphere.

Without the stability of greenhouse gases, the water vapor and cloud could not maintain current greenhouse effect. The Earth could be plunged back to ice age without stabilizing effect of non-condensing GHG. Carbon dioxide because of it being principal non-condensing greenhouse gas is the 'control knob' that governs Earth's temperature.

9.3 Impact of global warming on oceans

Oceans are largest reservoir of CO_2 and annually exchange 90 GtC of carbon at the interface of ocean and atmosphere which dwarfs anthropogenic contribution. Of the many impacts of rising greenhouse gases on oceans, the three most important ones are: (1) acidification of oceans, (2) rise of sea level, (3) changes in the 'thermohaline circulation'.

Ocean acidification

We are protected from severe consequences of the continuously rising emission of CO_2 (such as climate change) since a large fraction of emitted CO_2 is absorbed by oceans. However, the increasing dissolution of CO_2 is causing subtle chemical changes in the oceans with enormous implication on marine ecosystems.

The carbon in oceans remains in three forms dissolved CO_2, bicarbonates (HCO_3^-) and carbonates (CO_3^{2-}). After dissolution in oceans a fraction of CO_2 gets converted to carbonic acid (H_2CO_3) which in turn gets ionized to bicarbonate liberating a proton.

$$CO_2 + H_2O \rightleftharpoons H_2CO_3 \rightleftharpoons H^+ + HCO_3^- \quad (13)$$

The bicarbonate anion, in turn, gets ionized to carbonate ion liberating another proton (Eq. 14).

$$HCO_3^- \rightleftharpoons H^+ + CO_3^{2-} \quad (14)$$

All these species remains in equilibrium aqueous medium (Eq. 13 and 14). It is clear from Equations 13 and 14 that dissolution of CO_2 leads to lowering of pH of ocean due rise of proton (or hydronium ions) concentration. The natural ocean water pH generally persists in between 8.0 to 8.3. Studies have shown that oceans have already experienced 0.1 unit reduction in its pH since preindustrial times. It seems likely that the oceans pH would further drop by 0.3 units by the year 2100.

As per the Eq. 13 and 14, the equilibrium of the reactions and resultant concentration of various forms of carbon depends on pH of ocean water. The concentration of carbonates ions declines as pH of aqueous medium decreases. And decline of carbonate ion concentration in marine water has serious implication for marine ecosystems since it leads to dissolution of calcium carbonate (Eq. 15).

$$CaCO_3 \rightleftharpoons Ca^{2+} + CO_3^{2-} \quad (15)$$

The equilibrium shown in Eq. 15 shifts to right direction as concentration of carbonate ions decreases. Calcium carbonate is important material needed to build shell and other hard part marine organisms. The rising pH of seawater is affecting survival of shell forming organism due dissolution their hard shell. The marine organisms that are most affected due to lack of CO_3^{2-} ions are some phytoplankton species and small snails which are major source of food for marine fishes and mammals, including some species of whales. The coral reefs are also affected by decline of pH (See the Case Study below).

The dissolution of calcium carbonates also depends on temperature and pressure of marine water. High pressure and low temperature leads to dissolution of calcium carbonate shell of shell forming organisms. This is the cause of existence of 'saturation horizons' in oceans beyond which shell forming organisms often does not exist. The declining pH of oceans is also thinning up the shell friendly upper layer of oceans. The consequences of this thinning on marine ecosystem, is not understood fully.

Case Study: Mass coral bleaching and global warming

In 2016, most of coral reef ecosystems of tropics such as Great Barrier Reef suffered from mass bleaching. Though similar mass bleaching was also occurred in 1998 and 2002, but in 2016 mass bleaching, proportion of reef experiencing bleaching was four times higher than in 1998 and 2002. Only 8.9% corals of Great Barrier Reef were found without bleaching while during 2002 the percentage was 42.4% and in 1998 it was 44.7%.

The mass bleaching of 2016 was also accompanied by decline of carbonate budget of shallow fore- reef (outside part of reef or reef edge) of southern Maldives. This has led to reduction of rate of carbonate deposition of the shallow fore-reef from 5.92 kg $CaCO_3$ m^{-2} yr^{-1} to net negative at – 2.96

The major cause for mass bleaching was identified as heat stress caused by strong El-Nino event in the year 2015-2016. Due to heat stress corals shed their symbiotic algae which were responsible for giving festinating color to corals. The removal of symbiotic algae makes the coral physiologically week and they died if they remained bleached for long time. The decline of carbonate budget of shallow fore-reef of southern Maldives occurred due to killing of specific reef forming species. The mass bleaching of 2016 happed due to El-Nino (vide supra), but it was observed that rise in average global temperature is functionally changing biotic community of coral reef ecosystem (second in terms species richness after tropical forests) in Great Barrier Reef as thermal tolerances of different inhabitants of the coral reef ecosystem (corals, algae, fishes, invertebrates etc.) are different. With erosion of reef, its ecosystem services especially tourism and shoreline protection would also be lost.[3]

Rising sea level

Global warming is also heating oceanic water causing increase of volume of the water and decrease of the density of the water. This is the reason behind current 3 mm/yr rise in sea level. However, this contribution in sea level rise is dwarfed if the balance between glaciations and de-glaciations of ice sheets, glacier, and ice caps is tipped towards irreversible melting.

Almost all of the non oceanic freshwater is trapped in two major ice sheets: Antarctica and Greenland ice sheets. The Antarctica ice sheet stores enough water to raise sea level by around 58 m it is completely melted. The Greenland ice sheet are able to raise the sea level by around 7.4 m if is completely melted while ice caps and glaciers store water equivalent to 0.3 m rise in sea level. The impact of global warming on Antarctica and Greenland ice sheets is profoundly important for future of our coastal cities and cultural heritage.

The response of Antarctica ice sheet to global warming is nonlinear due to complex interaction between ocean, atmosphere, ice sheet, and solid Earth. Recent studies have found that West Antarctica Ice Sheet (WAIC) which rest on ocean floor may partially collapse (owing to marine ice sheet instability) if the average global temperature increases 2 ° C above preindustrial level. Involvement of many positive feedbacks (such as surface melt-elevation feedback where melting will increase as elevation of ice sheet decline due increase of temperature as we move towards Earth surface) and negative feedbacks (such as solid Earth rebound where unloaded Earth crust after loss of ice sheet mass would lead to drop in sea level) would cause the Antarctica ice sheet to respond differently under different ranges of global temperature rise. The melting of Antarctic ice sheet would cause a sea level rise by 1.3 m/ ° C for up to 2 ° C increase of mean global temperature from preindustrial level. The sea level would increase by 2.4 m/°C for temperature rise between 2°C to 6

°C and at rate of 10 m/°C for a temperature rise between 6°C to 9°C above preindustrial level due to melting of Antarctica ice sheet. At temperature more than 10°C above the preindustrial level, the whole Antarctica would become ice free.[4]

The impact of global warming on Greenland ice sheet could also be unprecedented. A recent study have found that under the most optimistic path of future increase of greenhouse gases (Representative Concentration Path or RCP2.6), the Greenland ice sheet would loss ice at a rate of 8,800 Gt (giga ton) per centaury by the year 2100. This rate of mass loss (per centaury) of Greenland ice sheet have not been observed in the last 12,000 years as predicted by combing climate model with experimental $\delta^{18}O$ data (ratio of $^{18}O/^{16}O$ with reference to standard expressed as part per thousand) obtained from ice cores of Greenland. The highest rate of mass loss during above period was found to be 6000 Gt per centaury which is similar to current rate of mass loss of 6100 Gt per centaury.[5]

Rising sea level would not just submerge coastal land, but combined effect of increase of sea surface temperature and sea level rise would also increase severity and frequency of tropical storms (see next section) affecting coastal cities and towns. It may result in large areas of densely populated coastline having to be abandoned. Given 20% of world population is living within 30 km of coastline, climate change can make tens of millions people to be displaced, resulting in a huge refugee (called climate change refugee) problem in coming future. Other impacts of rising sea level are shoreline erosion, inundation of coastal wetland, and increased salinity of estuaries and aquifers.

Thermohaline circulation

Thermohaline circulation is a measure circulation of ocean water from the Equator towards the poles. The water circulating in above gigantic flow is higher than water-flow through all the rivers of world (200,00,000 m^3 per second). In this circulation, warm surface ocean water from the Equator moves towards North Atlantic abyss near Greenland. Here the wind encourages evaporation of warm water and in the process more subsurface warm water emerges. The process liberates enough heat across North Atlantic making winter of Northern Europe 5°C to 10°C warmer than if there is no heat addition from warm ocean current. As the warm current moves towards pole more and more evaporation happens by blowing wind and finally the water becomes so cool and dense (due increase of salt concentration, hence the name contain word 'haline') that it sink down to ocean bottom.

The deep cold ocean water then moves southward towards tip of Africa. Some portion of the cold deep current emerges to surface near coast of India, but majority of cold water upwells in Pacific Ocean from where it restarts its journey back to North Atlantic (Fig. 8). This gigantic flow distribute heat around the globe and sink dissolved carbon dioxide in deep ocean including bringing nutrient deposited in the sediments of ocean bottom back to the surface.

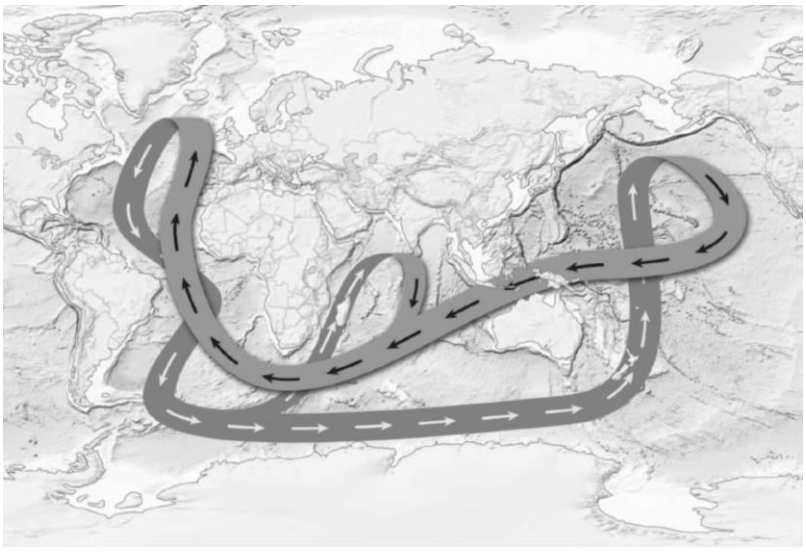


Figure 8: Thermohaline circulation or Atlantic conveyor belt. Arrows show flow of water. Orange is warm shallow current and blue is deep cold current. (Source: Science, Ref. 6)

The thermohaline cycle is important contributor in maintaining Earth's climate especially Northern Europe and northeast North America. Global warming induced change of precipitation and runoff pattern over North Atlantic and Greenland may discharge a lot of fresh water in North Atlantic which slow or stop the thermohaline cycle. In geological history of Earth, we have observed many stable states of the cycle in which it run at faster rate, at intermediate rate and at extremely slow rate. The transition between these states could in the span of few years. The shifting of thermohaline cycle

from one stable state to another one could lead to drastic change in Earth's climate as was believed to occur just after last glacial period. Some 11,000 years ago, due to stoppage of thermohaline cycle whole northern Europe and northeastern North America plunged back to ice age when the region was entering interglacial stage, glaciers were retreating and temperature were approaching to warmer level. The Greenland temperature drops by 6°C in less than 100 years and remained at that level for last 1000 years. The temperature jumped back to warmer level in just 20 years. Slowing of thermohaline cycle due to global warming would offset some but not all of the predicted regional warming that may happen if the thermohaline circulation remains intact.

9.4 Global warming and adverse weather events (climate change)

After discussing the impact of global warming on oceans, let us understand how rise in average global temperature could increase adverse weather events. We shall discus this by taking example of El Nino event which disturb the normal weather patterns in much of the globe including India.

El Nino event interfere with general circulation pattern of Earth. What is general circulation pattern?

General circulation pattern (or global circulation)

Global circulation is pattern of winds, low and high pressure zones in atmosphere that we observe around our Earth. The global circulation or general circulation pattern decides the major climatic zones which exist on our Earth.

Due to almost spherical shape of Earth, all parts of Earth does not receive same amount of solar energy. This, along with the tilt of axis of rotation of Earth forms a general atmospheric circulation pattern. Figure 9, shows the formation of high and low pressure zones and associated wind pattern when sun is just above the Equator (at equinox).

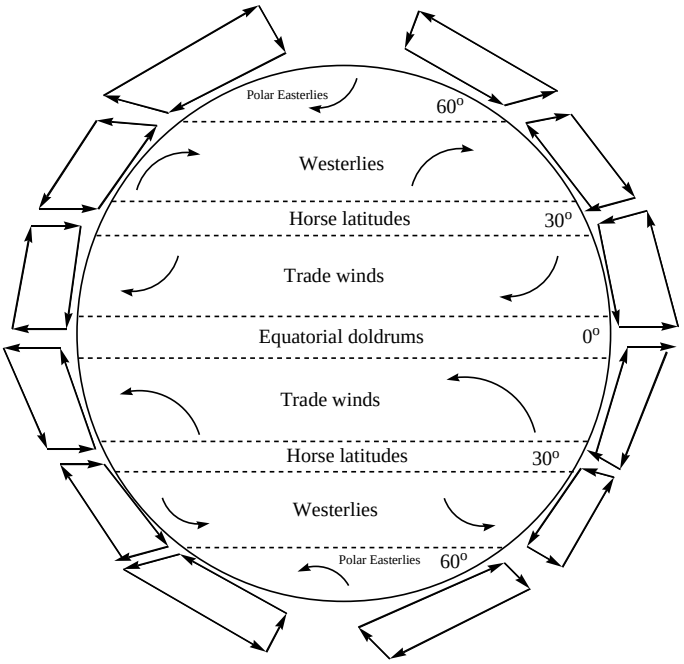


Figure 9: General circulation pattern which could be observed during equinox.

Regions around equator receive highest amount of solar energy. This causes warming of air masses near surface. The hot and less dense air rises vertically near equator and takes up a lot of moisture with it, during its rise over ocean surface. The vertically rising hot and moisture laden air got cooled near boundary of troposphere (around 10-12 km) and causes lot of precipitation in tropical latitude around equator. To replace the rising air a horizontal air near the Earth surface (called '*trade wind*') flow from the side of pole towards the equator. The vertically rising air over equator disperses towards north and south poles after reaching to near tropopause. The cool and dense air descends near 30°latitude, the location from where the surface air (in the form of trade wind) towards equator thus forming a closed cell called '*Hadley cell*'. Similar types of cells are formed (in a link) between 30° and 60°latitude and between 60°and pole (Fig. 9).

At 30°latitude the descending cool air got heats up as it reached towards surface. The hot air avoid the formation of cloud around this latitude which is reason that most of the great deserts (such as desert of southern California, the Thar Desert of India, the Sahara around 30° N and the Chilean

Desert, the Kalahari Desert in South Africa and great deserts of Australia around 30ºS) occurs around 30º latitude.

The warm surface air mass (westerlies) at 30ºmoves towards pole where it met with cold polar air mass. The mixing of warm and cold air mass lift the warm air and creates a stream of air near tropopause (7 km-12 km) called '*Polar Jet stream*' which is band of air moving around 60ºlatitude (low pressure zone) from west to east at speed reaching up to 440 km/hr. Like equatorial latitude, regions around 60ºlatitude tend to be moist due to rising air mass. The zones of high and low pressure (and consequently the wind pattern) shift towards North Pole as solar elevation increases during summer of northern hemisphere and towards southward during winter of northern hemisphere. The regions of vertical air flow near 0 º and 30 º latitude are called '*equatorial doldrums*' and '*horse latitudes*', respectively, due to no horizontal air flow.

Over above general circulation pattern are super imposed many coupled ocean-atmosphere oscillations which affect the location and consequently weather pressure zones described above. One of the important coupled atmosphere and ocean oscillation is El Niño Southern Oscillation (ENSO) which is responsible for affecting much of the globe.

El Niño and adverse weather events

El Niño and La Niña are two events of coupled ocean-atmosphere oscillation which encompass entire equatorial Pacific Ocean. The equatorial Pacific Ocean generally exists in three states: neutral, El Niño and La Niña. A neutral year is characterized by cool eastern equatorial Pacific and warm western Pacific. This general neutral state of Pacific is disturbed in every three to seven years by El Niño event. During the event sea surface temperature (SST) of normally cool eastern Pacific increases from normal level while western Pacific gets cooler than normal. The El Niño event is often followed by La Niña event where eastern Pacific sea surface temperature drops below normal temperature while western Pacific temperature gets higher than normal. This oscillation of state of equatorial Pacific is called El Niño Southern Oscillation (ENSO).

El Niño is Spanish word derived from phrase 'corriente del nino' which mean ocean current of Christ Child. It was first observed as warm ocean current by Peruvian Navy captain off the coast of South America around 1893 during Christmas time (December), so it was named ocean current of Christ Child. The rise of temperature of eastern Pacific by more than 3ºC lead to an extreme El Niño as is characterized by 1982/83 and 1997/98 El Niño.

Due to presence of higher land mass (Maritime continent) in western equatorial Pacific, temperature remains higher while upwelling of cold subsurface water of thermohaline circulation near eastern equatorial Pacific lead to low temperature in this part of equatorial Pacific. Easterly trade wind further piles up hot sea surface water towards western Pacific.

The El Niño event started by weakening of easterly trade wind and initiation of westerly wind event (WWE) which leads to warming of eastern Pacific. The warming of eastern equatorial Pacific leads to weakening of Walker circulation. Walker circulation (an equator wise loop of atmospheric circulation consisting easterly trade wind) leads to high rain fall over countries of Maritime continent (such as Indonesia) while creating dry conditions over eastern Pacific regions consisting of northern Peru and Ecuador. Warming of normally cool eastern Pacific also suppresses upwelling of cold subsurface water of thermohaline cycle.

The extreme El Niño event also pulls Intertropical Convergence Zone (ITCZ) and South Pacific Convergence Zone (SPCZ) towards equator. Intertropical Convergence Zone (ITCZ) is a rain band or low pressure monsoon trough and follows the annual northward and southward elevation of the sun. ITCZ is responsible for Indian summer monsoon as during Indian summer it shifted 20º to 25º N over North Indian Plain. Since western and central Pacific warm pool location is south of equator, it leads to its mergence with mid-latitude storm track forming a diagonal band of deep convection and heavy rainfall called South Pacific Convergence Zone (SPCZ).

The equator ward shift of ITCZ and zonal (west to east) shift of SPCZ due to extreme El Niño results in catastrophic flood in normally cold and dry eastern equatorial Pacific regions of Ecuador and northern Peru. Further, movement of ITCZ from its original position cause drought in the Central America, while zonal shift of SPCZ results in drought in northern Australia and Indonesia. The shift of ITCZ also causes flood in southwest US through some teleconnection. In general extreme El Niño creates famine like condition in many parts of world due to flood and drought (Fig. 10).

The extreme El Niño event of 1997/1998 caused a loss of US$ 34-35 billion in terms of damage to infrastructure and property, and claimed 23,000 lives.[7]

	The drought like conditions in Southeast Asia caused by 2014-2016 El Niño resulted in massive forest fire in the region and sent 3 billion tons of CO_2 in atmosphere.[8]

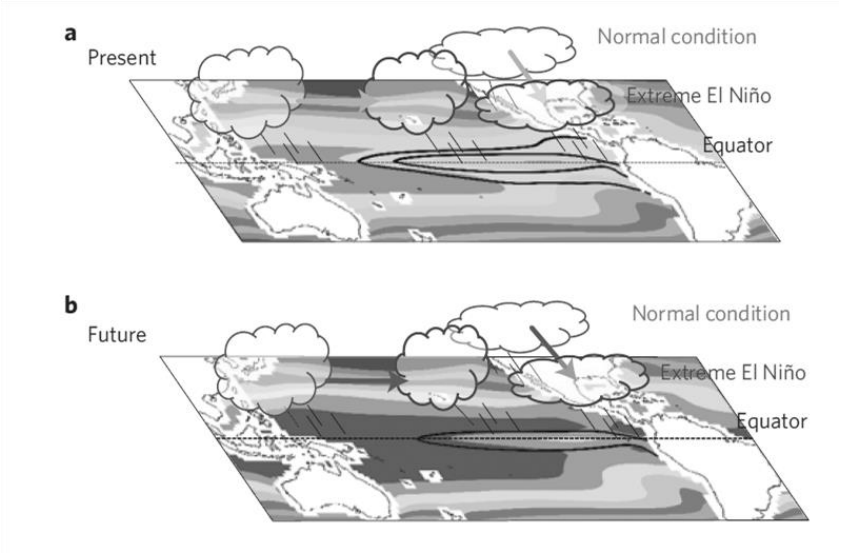


Figure 10: Schematic showing (a) normal (blue cloud) and El Niño (red cloud) condition over equatorial Pacific, (b) Impact of global warming on El Niño condition. (Source: Nature Climate Change, Ref. 7)

Extreme El Niño and global warming

Extreme El Niño events which are characterized by warming of eastern Pacific by more than 3°C (for example, 1997/1998 event) has a probability of just one event in 187.5 years.[9] It is due to presence of barrier of zonal (west to east) and meridional (temperature change from 8°N to the Equator) SST gradient (Fig. 10a, see the color coding: red is warmest and blue is coolest) which stops the shifting of convection zones towards the Equator. Radiative forcing caused by rising greenhouse gases is causing warming everywhere, but it is increasing temperature of eastern equatorial Pacific at faster rate than everywhere else. This unequal warming is diminishing zonal and meridional SST gradient (Fig. 10b). The decrease of the SST gradients can trigger an extreme El Niño for very small variation in sea surface temperature leading to increase in probability from one event in 187.5 years to one event in 48 years as predicted by climate modeling (coupled global circulation model).

The El Niño caused shifting of ITCZ towards the Equator also affects summer monsoon in India. The shifting leads to delay in arrival of monsoon and cause deficiency in rainfall in India. The extreme La Niña followed by El Niño event leads to severe drought in southwest US and eastern Pacific, while flood in western Pacific region. Climate modeling has predicted 75% increase in extreme La Niña followed by extreme El Niño.[9] ENSO is not the only coupled atmospheric-ocean oscillation which is being disturbed by global warming other coupled atmosphere-ocean circulation such as Madden-Julian Oscillation (MJO), Indian Ocean Dipole (IOD), North Atlantic Oscillation are also getting disturbed leading to more extreme weather events.

Intensification of cyclones

Rising sea surface temperature due to greenhouse gas induced global warming, especially at sea areas covered by low pressure convection zones (e.g. ITCZ, which is fertile ground of genesis of cyclones), is increasing both the intensity (especially rainfall) and depth of progression of cyclones after their landfall. One of the causes of the rise of frequency of cyclonic events is the requirement of sea surface temperature more than 27°C for genesis of cyclones which is being easily fulfilled by increasing probability of extreme swing in coupled atmosphere-ocean circulations such as ENSO. For example, there is 52% rise in cyclones formed in Arabian Sea affecting West Coast of India.[10]

The supply of more moisture (due to more evaporation caused by warmer sea surface) in the building up tropical disturbance leads to enhancement of wind speed (as more heat is released by condensing water vapor) and amount of rain fall of cyclonic storms. Mostly cyclone subsided soon after their landfall since energy supplied by ocean moisture gets snapped. The supply of extra energy by addition of more water vapor is causing slower decay of cyclones after their landfall. For example, coast of East and Southeast Asia have experienced 12-15% rise in intensity of typhoons hitting the in

last 37 years with the proportion of storms with category 4 and 5 is doubled and even tripped in some places.[11] The rise of sea level is also increasing severity of coastal flooding by increasing storm surges which can easily cross levees made along coast line for protecting coastal cities from inundation (see also Unit 13).

9.5 Mitigation strategies for climate change

In above two sections we have learned how rise of greenhouse gases and associated global warming is increasing adverse weather events and may cause submergence of coastal areas. The rise of average global temperature and associated change in average rainfall would also increase rate of biodiversity loss. All these changes can damage the global and regional economies and would reduce overall human welfare. There are two major ways by which we can mitigate impact of climate change:

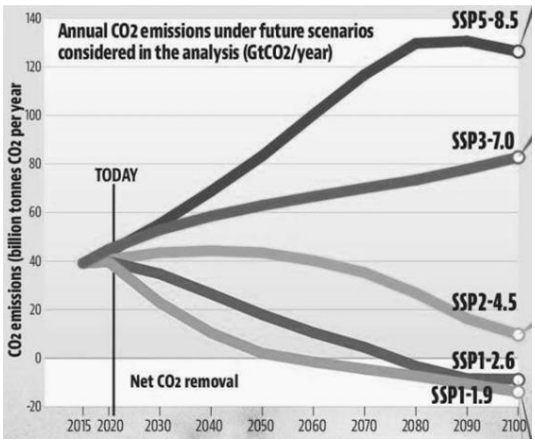
(1) control of greenhouse gases,

(2) minimization of impact of rising greenhouse gases.

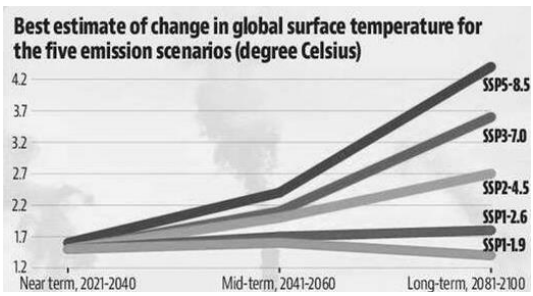
The rise of concentration of greenhouse gases in atmosphere cannot be just controlled by stabilizing the anthropogenic emission rate at present level since greenhouse gases accumulate in atmosphere due to difference in the rate of uptake by carbon sink and anthropogenic emission rate as discussed in section 9.3. We have to work in a way so that rate of emission gets equalized with rate of absorption of carbon dioxide.

Based on future changes in socio-economic conditions (population, urban density, land use and wealth) and climate action policies, five major paths in future changes in greenhouse gas emissions with associated radiative forcing are recently calculated by IPCC. The pathways are initially labeled as SSP1 (Shared Socioeconomic Pathway 1) to SSP5 (Ref. 12) and after combining the changes in radiative forcing by following these paths, five most representative ones are labeled as SSP1-1.9, SSP1-2.6, SSP2-4.5, SSP3-7.0 and SSP5-8.5. Previously these pathways were called as RCP (Representative Concentration Pathways) which lacked socioeconomic dimension and only include possible development trajectories of main forcing agents.

The change of annual emission rate of carbon dioxide under above mentioned scenarios is shown in Figure 11a. The corresponding rise in average surface global temperature is shown in Figure 11b.



(A)



(B)

Figure 11: (A) Change in annual CO_2 emission under future scenarios, (B) Change in global surface temperature under corresponding scenarios. (Source: Hindustan Times)

Two optimistic scenarios (SSP1-1.9 and SSP1-2.6) where rise of average global surface temperature would be below 2°C till the end of 21st century (also called sustainability pathways) requires fast reduction of anthropogenic CO_2 in a way that till 2050 we could reach to net zero emission.

Following mitigation strategies could be utilized for achieving net zero emission.

1. Carbon capture and storage (CCS)

2. Fuel switching

3. Demand reduction

Carbon capture and storage (also termed carbon sequestration) involve capture of carbon dioxide generated in coal fired power plants and other industrial operations. The stored CO_2 could be used as feed stock for bulk chemical manufacturing, growth of algal biomass to generate biofuel, or it could be buried deep inside earth.

Fuel switching involves use of energy from non-fossil fuel sources (e.g. nuclear, wind, solar, biomass, geothermal, and hydro). Demand reduction could be achieved by increasing the efficiency with which we use energy and through socioeconomic changes such promotion of resource conservation, shift of economy from manufacturing to service sector driven.

There is a scenario (SSP5) where we can use fossil fuel in unrestricted manner for growth of global economy in a participatory manner. The wealth generated could be utilized for rapid technological progress and development of human capital. This development fueled by fossil fuel could lead to highest rise of CO_2 in all possible scenarios with corresponding rise in average global temperature to 4.4°C till 2100. It is suggested in this scenario of rapid growth of global economy we can save avoid harmful impact of climate change by use of geoengineering. One such geoengineering based adaptation is use of geoenginnering of polar glaciers to stop their catastrophic melting to slow the sea level rise (Fig. 12).

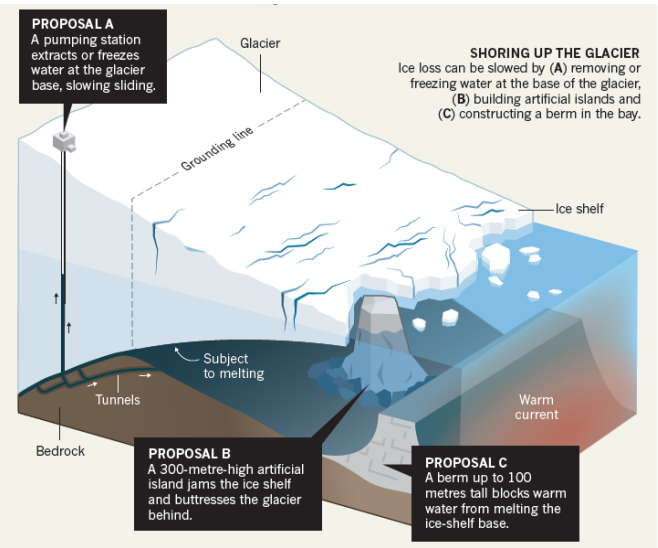


Figure 12: Geo-engineering of polar glaciers to slow sea level rise. (Source: Nature, Ref. 13)

This could be accomplished by extracting or freezing warm water entering inside base of glaciers (Proposal A, Fig. 12). The other options are construction of artificial island which can jam the slide of loosened glaciers towards low latitude warm water (Proposal B, Fig. 12) or construction of a berm up to 100 m tall which can block entry of warm water below ice-self base.

9.6 UV radiation

Ozone depletion is another problem caused by some greenhouse gases such as CFCs, halons, nitrous oxide. The depletion of ozone layer in stratosphere is responsible for increase of UV (Ultra Violate) radiations reaching to Earth's surface. The rise of UV radiation on Earth's surface is harmful to animals and plants including humans. Let us first understand what UV radiations are.

Solar energy coming from sun is in the form of electromagnetic radiation which is made up of three major components. As the sun rises it made everything visible, it is due to presence of visible light (electromagnetic radiation of wave length from 700 nm to 400 nm). Our eyes can recognize electromagnetic radiation which ranges from 700 nm (the wavelength of red light) and 400 nm (the wavelength of violate light).

The electromagnetic radiation is made up of oscillating electric and magnetic fields which behave as particle (called photon) in some phenomenon (such as photoelectric effect) and as wave in other phenomenon (such as diffraction of light). Or we can say electromagnetic radiations possess dual nature of wave and particle.

The energy of a photon is given by

$$E = h\nu = h\frac{c}{\lambda} \quad (16)$$

where

h = Plank's constant (6.626×10^{-34} Js)

c = speed of light (2.997×10^{8} m/s)

v = frequency (s^{-1} or Hertz)

λ = wavelength (m)

The electromagnetic radiation of wavelength above 700 nm is not visible to our eye and it is called infrared (IR) radiation. Similarly, electromagnetic radiation of wavelength below 400 nm is also not visible to our eyes and it is termed as ultraviolate or UV radiation (Fig. 13).

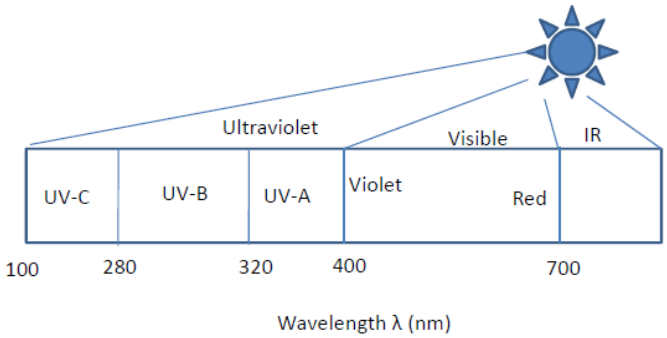


Figure 13: Solar spectrum made up of Visible, UV, and IR radiations.

As is clear from Equation 16, with decline of wavelength (λ) of radiation its frequency (v) and consequently its energy of photons increases. Hence, low wavelength UV radiations have more energy than IR and visible radiation. Based on energy of UV radiations and their impact on living beings these are divided in three categories: UV-A, UV-B, and UV-C (Fig. 13).

UV-A (400 nm to 320 nm) comprise 99% of all UV radiation which reaches to Earth's surface. The radiation penetrates deep inside human skin and causes photoaging and tanning of human skin. Small exposure to UV-A is good for human health as it induces synthesis of vitamin D. However, high exposure to UV-A radiations may cause DNA damage and possibly cancer. UV-B (320 nm to 280 nm) is most dangerous portion of UV spectrum in terms of its impact on life on Earth since our atmosphere effectively shields us from most energetic portion UV spectrum; the UV-C radiation (280 nm to 100 nm).

UV-B radiations induces reddening of skin (erythema) and reduces production of vitamin D for short term exposure, while long term exposure causes skin cancer, cataract and suppression of immune system. Though UV-C radiation does not reach to Earth's surface, but artificially created UV-C radiation is effective disinfectant for water treatment and other germicidal applications due to their ability to readily destroy DNA of living cells.

9.7 Ozone layer: Protective shield

We are protected from harmful UV radiations due to continuous generation and removal of ozone (O_3) in stratosphere of atmosphere. The generation of ozone is started from splitting of oxygen molecules by photons (of energy hv) short wavelength UV-C radiations into atomic oxygen (Eq. 17).

$$O_2 + h\nu \rightarrow 2\,'O' \quad (17)$$

Diatomic oxygen has maximum absorption at 140 nm in its UV absorption spectra and is very effective in absorbing UV-C radiation in the range 130 nm to 180 nm. Though, it is able to absorb UV radiation till 242 nm.

The oxygen atoms formed by Eq. 17 rapidly reacts with another oxygen molecule forming ozone (Eq. 18).

$$O + O_2 + M \rightarrow O_3 + M \quad (18)$$

M in Eq. 18 is third body (usually N_2 molecule) which is needed to carry heat produced during reaction which stops cleavage of ozone back to oxygen. Ozone formed in Equation 18 also has its characteristics UV absorption spectrum which extends from 200 nm to 320 nm with peak at 255 nm. The photo excited ozone gets split back to oxygen molecule and oxygen atom (Eq. 19).

$$O_3 + h\nu \rightarrow O_2 + O \quad (19)$$

Ozone effectively removes UV-C radiations ranging from 200 nm to 280 nm and some of the UV-B radiation before it reaches to Earth's surface. The reactions shown in Eqs. 17 to 19 remove all of UV-C radiation and more harmful UV-B radiation from solar radiations when it passes from stratosphere. The absorbed energy of UV photons gets converted to heat which is why stratosphere shows temperature inversion where temperature increases with altitude. The temperature inversion traps pollutants which drifted in it from troposphere.

The effectiveness of chemical processes mentioned above (Eq.17 to 18) is shown in Figure 14. It is clear from the figure that radiation of wavelength below around 320 nm rapidly declines and ozone layer shields us from almost all radiations below 290 nm making life possible on Earth.

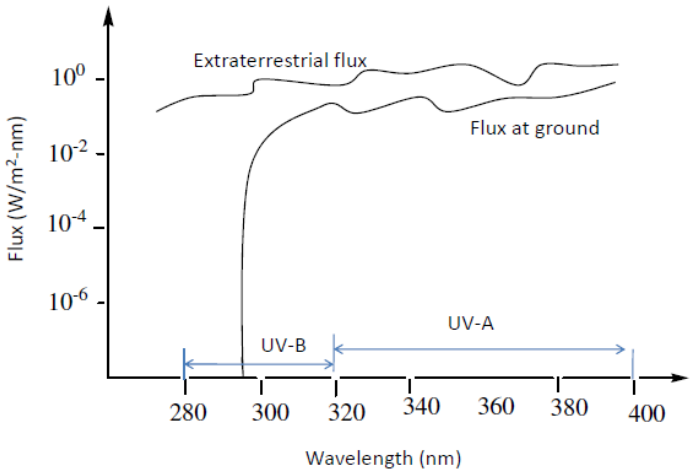


Figure 14: The ozone cutoff: Extraterrestrial flux and typical flux reaching to Earth's surface during clear sky and sun at 60°from zenith. (Source: Ref. 14)

Depletion of ozone layer

As we have seen above the dynamic formation and destruction of ozone in stratosphere protects us energetic and harmful UV radiations. However, the natural dynamics of ozone is being affected by addition of many man-made gases in stratosphere. One of the major disturbances is caused by chlorine and bromine containing halocarbons which generate chlorine and bromine atoms in stratosphere. These atoms work as catalyst in degradation of ozone and cause severe decline in ozone concentration in stratosphere.

In halocarbon, chlorofluorocarbons (CFCs) are highly inert gases which are used as working substance in air-conditioners, refrigerators (due to high Joule-Kelvin effect or cooling in expansion), and in making foamed plastics. These substances (first created in 1930s) were considered as wonder chemicals since they have replaced toxic, explosive and unstable refrigerants and assisted in wide spread expansion of luxuries of refrigeration and air conditioning. The inertness of CFCs which helped in development of safe ACs and refrigerators was found to be most destructive property for stratospheric ozone.

Due to inertness and insolubility of CFCs these chemicals gets accumulated in troposphere. The long residence time of these gases in troposphere allowed them to be drifted in stratosphere located 10 km to 50 km above sea level. The presence of high amount of energetic UV radiation in stratosphere

causes photolysis of CFCs. A typical photolysis reaction is shown in Eq. 20, where CFC-12 (CCl_2F_2) is destroyed by photolysis by UV-C.

$$CCl_2F_2 + \text{UV-C} \rightarrow CClF_2 + Cl \quad (20)$$

Chlorine atoms generated by Equation 20, soon reacts with ozone molecule generating chlorine oxide (ClO) free radical and oxygen molecule (Eq. 21). However, chlorine oxide free radicals react with O atoms abundantly present in stratosphere regenerating back Cl atoms (Eq. 22) which again react with ozone molecule.

$$Cl + O_3 \rightarrow ClO + O_2 \quad (21)$$

$$ClO + O \rightarrow Cl + O_2 \quad (22)$$

Net reaction: $O_3 + O \rightarrow 2O_2$ (23)

As shown in reactions (21) to (23), chlorine works as catalyst and a single chlorine atom can destroys tens of millions of ozone molecules before it got terminated (or stabilized) by its reaction with CH_4 (Eq. 24) which drift in stratosphere from troposphere. So, methane is a potent greenhouse gas causing climate change but helps in inhibiting ozone depletion in stratosphere.

$$Cl + CH_4 \rightarrow HCl + CH_3 \quad (24)$$

Water soluble HCl diffuses to troposphere where it is removed from atmosphere through precipitation. Other free radical ClO is terminated by its reaction with NO_2 forming chlorine nitrate (Eq. 25).

$$ClO + NO_2 \rightarrow ClONO_2 \quad (25)$$

At any given time 99% of all chlorine species remained in inactive forms of HCl and chlorine nitrate in stratosphere. The solid particles of polar stratospheric cloud (PSC, see next section) and sulfate particles works as heterogeneous catalysts and promote photolysis of inactive chlorine species back to active forms (Cl and ClO).

In comparison to chlorine containing compounds bromine containing compounds are more potent in ozone depletion. Bromine atoms generated from organobromine compounds (halons such as methyl bromide) also work as catalytic species as shown in reactions (26) and (27).

$$Br + O_3 \rightarrow BrO + O_2 \quad (26)$$

$$BrO + ClO \rightarrow Br + O_2 \quad (27)$$

Bromine also continue to destroy ozone till it reacts with methane and gets converted to HBr. Hydrogen bromide is less stable than hydrogen chloride (HCl) and it quickly decomposed by photolysis back to Br atoms. Major source of bromine atoms in stratosphere is methyl bromide about half of which comes from oceans while approximately next half comes from anthropogenic sources. Methyl bromide used as soil fumigants especially for crops which grows near ground and to fumigate commodities before shipping them. Other sources of bromine in stratosphere are halons which are used as fire extinguisher. Halons as liquefied compressed gas are used as fire retardants in electronic industry and in aircrafts as these do not leave any residue on assets being protected. Due to their ozone depletion potential the production of halons has been ceased in 1994 while that of methyl bromide on 2005.

9.8 Antarctic ozone hole

Ozone depleting gases are drifted in whole stratosphere (surrounding the Earth) uniformly, but it looks curious why ozone hole is only formed over Antarctica. Let us try to understand answer of above question.

As discussed above 99% of all chlorine in stratosphere remained inactive as HCl and $ClONO_2$. The specific atmospheric conditions occurring during the winter of Antarctica catalyze the decomposition of inactive hydrogen chloride and chlorine nitrate back to active chlorine species.

Antarctica is the coldest place of Earth and due to its location around 90°latitude there occurs only two seasons: six month winter which is always dark and six month summer which is always sunny. During winter of Antarctica a polar vortex circulate around it which virtually isolates the air above continent from rest of the Earth. The temperature in polar vortex drops down below -90°C. This extreme temperature results in formation clouds in stratosphere even though presence of very dry air in stratosphere. The polar stratospheric clouds (PSC) provides surface for adsorption of HCl and

$ClONO_2$ (inactive chlorine reservoir) which reacts with each other and water to release chlorine gas in stratosphere (Eqs. 28 to 30).

$$ClONO_2 + H_2O \rightarrow HOCl + HNO_3 \quad (28)$$

$$HOCl + HCl \rightarrow Cl_2 + H_2O \quad (29)$$

$$ClONO_2 + HCl \rightarrow Cl_2 + HNO_3 \quad (30)$$

As the sun rises in Antarctic spring in September the chlorine gas which accumulated during Antarctic winter photolytically decomposes generating large amount of catalytic Cl atoms (Eq. 31).

$$Cl_2 + hv \rightarrow 2\ 'Cl' \quad (31)$$

High amount of catalytic chlorine substantially reduces stratospheric ozone over Antarctica as per the reactions (21) to (23). Depletion of ozone in isolated stratospheric air (termed ozone hole) continue till HNO_3 gets photolyzed generating NO_2 to trap ClO radicals and Cl atoms get trapped in the form of HCl. The rise of temperature in late spring finally breaks down polar vortex and ozone depleted air moves from polar region to mid-latitude affecting countries like Australia and New Zealand. Decrease of ozone due to spread of ozone depleted air from Antarctic ozone hole results in around 20% rise in UV radiations over Australia. The entire ozone-hole cycle typically last from mid-August until the end of November.

The combination of land and ocean area over Arctic results in warmer temperature and much less polar vortex which do not allow formation of polar stratospheric clouds over North Pole. This causes comparatively much less (but still significant) thinning of ozone during spring of Northern Hemisphere. There is concern that rise of greenhouse effect can cool stratosphere which would make an Arctic hole more likely. If that happens far more people would be exposed to elevated UV radiation.

Ozone in atmosphere is measured in Dobson unit (DU) by Dobson ultraviolet spectrometer (developed by G.M.B. Dobson). 1 DU = 1 ppb (parts per billion) O_3. Ozone hole is defined as regions within which ozone level is below 220 DU.

9.9 Impact of UV Radiation on Human Health

The damage to life caused by UV radiation increases exponentially as the wavelength of radiation declines below 320 nm (approx.) and enters in UV-B region. Hence, slight elevation in UV-B radiation reaching to Earth's surface can cause more damage to life forms then by similar increase of radiation in UV-A or visible region. If we combine biological action spectra (relative damage caused to DNA, human skin and plant with respect to wavelength of solar irradiance) with solar irradiance reaching to Earth's surface then we obtain a biologically weighted solar irradiance (Fig. 15). As is clear from Figure 15, a slight increase of UV-B irradiance on Earth surface can have large change in biological weighted irradiance.

Much of our concern to increasing exposure to UV radiation is focused on rise in probability of developing skin cancer. Skin cancers are of two types: melanoma and non-melanoma. Non-melanoma characterized by basal cell and squamous cell carcinoma are more common, while much more life threatening malignant melanoma are rare. Basal cell carcinoma (BCC) account for about 75% of skin cancer which are slow growing and therefore treatable. Squamous cell carcinoma (SCC) accounts for approximately 20% cases of skin cancer and these can also be cured if treated early. Remaining cases of skin cancers (about 5%) are life threatening melanoma, as it metastasizes easily.

As per epidemiological studies an increase of 1% in UV-B radiation is linked with 0.5% increase in incidence rate of melanoma and 2.5% increase in non-melanoma. People with fair complexion are more affected with both types of skin cancers than individuals who have more protective pigment, melanin.

Exposure to UV radiation also leads to ocular damage (cataract and retinal degeneration) and immune system suppression in humans. UV-B radiation also reduces photosynthesis and other plant processes both in terrestrial and aquatic plants. UV radiations have ability to penetrate ecologically significant depth of aquatic ecosystems. One of the causes which make amphibian taxa facing highest threat of extinction is elevation of UV radiation. Eggs of amphibian have little protection to UV-B irradiation and the impact is higher in high altitude regions where the solar exposure is greatest.

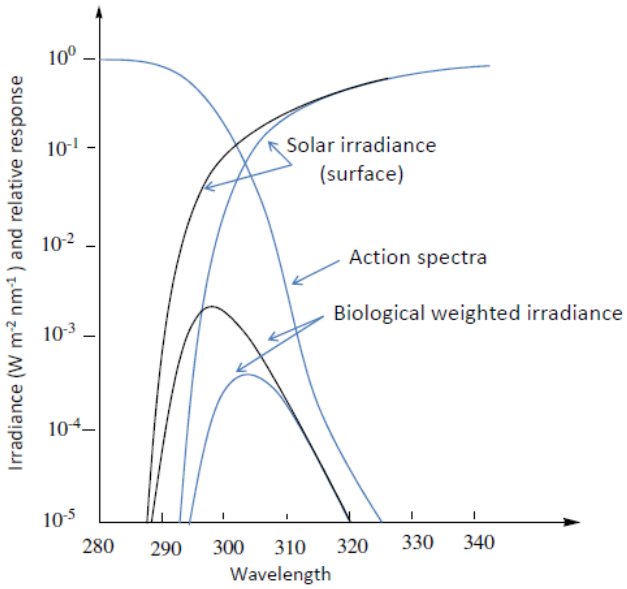


Figure 15: Biological weighted irradiance combining action spectra with solar irradiance. The blue curves indicate irradiance under normal ozone condition while black line corresponds to a reduction in ozone. (Source: Ref. 1)

To alert general public about exposure to UV radiation, a simple UV index is created. UV index is a non-dimensional number in the range from 0-12 which tells us erythemal (erythema: reddening of skin) weighted irradiance (at noon) expected for the following day.

UV index (UVI) is calculated by integrating (summing up) products of strength of solar radiation at a given wavelength and value of erythema weighting factor at that wavelength, in the range of 250 nm to 400 nm. The value of integration is then divided by constant to provide final values of UVI in the range 0-12.

Forecast of UV index through newspaper and web portal is now routine in many countries especially countries in Southern Hemisphere such as Australia (the country has highest rate of skin cancer in the world)[15], New Zealand, Chili. The UV index is also described by categories "Low" to "Extreme" which are based on time on time needed for fair-skinned person to get sunburned (Fig. 16).

UV Index	Category Descriptor	Sunburn Time
1-2	Low	More than 1 hr
3-5	Moderate	45 min
6-7	High	30 min
8-10	Very high	15 min
11+	Extreme	Less than 10 min

Figure 16: UV index with corresponding exposure level and sunburn warning as per WHO.

9.10 Acid rain and its formation

Acid rain is one of the many forms of general phenomenon called *acid precipitation*. The other forms of acid precipitation are snow, mist, and fog that are more acidic than usual. Since dry acidic particles are also found in atmosphere, so a combination of dry acidic particles fallout and acid precipitation is together called *acid deposition*. The phenomenon of acid deposition was first recognized by Swedish scientist Swante Odén in 1960s through his observation of acidification of acidification of lakes in Scandinavia. The discovery of acid deposition phenomenon by Swante Odén is resulted in careful monitoring of phenomenon in many parts of world. Now we know that broad area of North America, as well as most of the Europe and other industrialized regions of world have experienced acid precipitation that is 10 to 1000 times more acidic than usual. India is also experiencing decreasing trend in decadal mean pH (see below) of rain water as studied by Indian Institute of Tropical Meteorology, Pune.

Acid rain and pH

The acidity of aqueous solutions including rain water is measured expressed as pH which is negative logarithm (on base 10) of hydrogen ion concentration of aqueous solution or

$$pH = -\log [H^+] \quad (32)$$

where

$[H^+]$ is molar concentration of hydrogen ions.

The pH values ranged from 0 (highly acidic) to 7 (neutral) to 14 (highly basic). As pH increases from 0 to 7 the concentration of H^+ ions declines and solution becomes less acidic. In variation of pH from 7 to 14, the concentration of H^+ ions further declines, but concentration of OH^- ions increases and solution becomes more basic. A pH value of 1 means that concentration of H^+ ions is 1 mole per liter (mol/L) or 10^{-1} g/L, while for a pH value of 2 the concentration becomes 10^{-2} g/L. So, a change of one pH unit creates a tenfold difference in hydrogen ion concentration.

Normal rain water which does not contain any pollutant is naturally acidic since it dissolves carbon dioxide. Carbon dioxide reacts with water and generates carbonic acid which makes water acidic (Eq. 33) with pH around 5.6.

$$H_2O + CO_2 \rightarrow H_2CO_3 \quad (33)$$

Any rainfall or precipitation with pH below 5.5 is considered acidic. Acid precipitation has been the norm since middle of 20th centaury in most of the developed world (North America and Europe). Many areas of eastern North America once regularly received rainfall of pH 4 and occasionally of as low as 3.0. The region from British Isles to central Russia also suffered from heavy rainfall in later half of 20th century. Acid precipitation is now declining in North America and Europe; however it is rising in India and China due to increasing utilization of coal.

Sources of acid deposition

If we analyze the water from acid precipitation then we can found two acids; sulfuric acid and nitric acid as major constituents responsible for decreasing pH of acid precipitation. Sulfuric and nitric acids are secondary air pollutants which are formed from sulfur dioxide and nitrogen oxides released in atmosphere both from natural and anthropogenic sources. Sulfur dioxide (around 92% of which is contributed by coal fired power plants and industries dependent on coal) reacts with $OH^\bullet$ free radicals and forms sulfuric acid as reactions (34) to (36).

$$SO_2 + OH^\bullet \rightarrow HOSO_2^\bullet \quad (34)$$

$$HOSO_2^\bullet + O_2 \rightarrow SO_3 + HOO^\bullet \quad (35)$$

$$SO_3 + H_2O \rightarrow H_2SO_4 \quad (36)$$

Sulfur dioxide reacts with hydroxyl free radicals and generates $HOSO_2^\bullet$ (Eq. 34) which further reacts with oxygen creating sulfur trioxide (Eq. 35). Sulfur trioxide is highly reactive and water soluble gas which after reaction in water forms sulfuric acid (Eq. 36).

Nitrogen oxide in the form of NO_2 (around 51% of which traced to transportation emission and 41% to fuel combustion at fixed site) reacts with $OH^\bullet$ free radicals and form nitric acid (Eq. 37).

$$NO_2 + OH^\bullet \rightarrow HNO_3 \quad (37)$$

The two acids gets dissolved in water or adsorbed on particles and return to ground in the form of acid deposition. It takes around a week for conversion of nitrogen and sulfur oxides to corresponding acids.

The third important contributor to acidification is microbial oxidation of ammonia to nitrates. Major source of ammonia is use of nitrogen fertilizers (e.g. urea and ammonium sulfate) and livestock. Urea is decomposed to ammonia species possessing ureas enzymes. Ammonia, whether present in soil, water or atmosphere is finally oxidized by microbial processes to nitrate as per reactions (38) and (39).

$$2NH_3 + 3O_2 \xrightarrow{\text{Nitrosomonas}} 2\,NO_2^- + 2H^+ + 2H_2O \quad (38)$$

$$2NO_2^- + O_2 \xrightarrow{\text{Nitrobacter}} 2NO_3^- \quad (39)$$

It is clear from reaction (38) that oxidation of ammonia by nitrosomonas liberates hydrogen ions in water (present in soil or atmosphere), thus reduces its pH.

Natural sources contribute annually 50-70 million tons of sulfur dioxide (from volcano, sea spray, and microbial processes) 30-40 million tons of nitrogen dioxide (from lightening, the burning of biomass, and microbial processes). Anthropogenic sources annually contribute around 115 million tons of sulfur dioxide, 60-70 million tons of nitrogen oxides, and about 50 million tons of ammonia. Due to concentration of anthropogenic emission over industrial and agricultural regions, these are major contributor of acid deposition phenomenon over industrial regions than natural sources which spread out in whole environment of Earth. Further, there is six fold increases in level of anthropogenic oxides since 1900 while emission from natural sources remained fairly constant.

9.11 Impact of acid rain on terrestrial ecosystems and materials

Acid precipitation affects terrestrial ecosystem in two ways:

(1) by directly interacting with leaves of trees,

(2) by disturbing soil chemistry. Some species of plants such as red spruce and sugar maple get destroyed by persistent acid rain due to leaching calcium from plant's leaves.

Lack of calcium of leaves make these trees which are part of temperate forest ecosystem vulnerable for winter freezing.

The greatest impact to terrestrial ecosystems by persistent acid rain is caused by its interaction with soil. Initially acidic water added from acid precipitation gets neutralized by buffer chemicals (such as $CaCO_3$) present in the soil. However, when all these buffer chemicals gets neutralized and leached from the soil, further addition of acidic water from acid precipitation starts to dissolve cations adsorbed on humus such K^+, Ca^{2+}, Mg^{2+} etc. which are important plant nutrients. The important nutrient cations get replaced by excess protons present in acid rain and leached below the reach of plant's roots. Further, addition of acid from acid precipitation also starts to dissolve heavy metals such as Al^{3+}. The combination of toxicity of Al^{3+} and scarcity Ca^{2+} lead to recued plant growth.

Acid rain also dissolves stones such as limestone and marble, both are basically calcium carbonate which is favored material for building of monuments (Eq. 40). At pH less than 5.5, acid rain also attack concrete and mortar. The calcium hydroxide which constitutes 20 to 25% volume of hydrated cement phase of concrete and mortar reacts especially with sulfuric acid present in acid rain and is converted to more soluble calcium sulfate or $CaSO_4$ (Eq. 41). Being soluble in water, $CaSO_4$ gets leached out from concrete making it porous. $CaSO_4$ further attack (sulfate attack) hydrated aluminate (component of hydrated cement) of concrete generating high volume calcium sulfoaluminate which cracks the concrete.

$$CaCO_3 + H_2SO_4 \rightarrow CaSO_4 + CO_2 + H_2O \quad (40)$$

$$Ca(OH)_2 + H_2SO_4 \rightarrow CaSO_4 + 2H_2O \quad (41)$$

Acid rain also increases corrosion of metal and alloys. Presence of acid in water increases oxidation potential of aerated water and alloys having lesser tendency to corrode also start to corrode. The potential of a substance to corrode (oxidize) a metal or alloys is measured by its standard reduction potential. As shown in reactions below, the aerated water containing protons (Eq. 43) has much higher potential to corrode than simple aerated water (Eq. 42).

$$O_2 + 2H_2O + 4e^- \rightarrow 4OH^- \qquad E^o = +0.40V \quad (42)$$

$$O_2 + 4H^+ + 4e^- \rightarrow 4H_2O \qquad E^o = +1.23V \quad (43)$$

9.12 Impact of Acid Rain on Aquatic Ecosystems

Generally the pH of freshwater lakes, ponds, and streams range from 6 to 8. The pH of water bodies is important for survival of aquatic species as it affects enzyme, hormones and other proteins essential for vital life processes of the species. The persistent acid rain leads to decline of pH of water bodies. The bodies of aquatic species have ability to limit their internal body pH within narrow range. The continuously low pH overwhelms body mechanism to neutralize excess acid.

In many amphibian species fertilization (fusion of egg with sperm) occurs outside their body in water. The sperm, egg and developing young of these species are especially sensitive to decrease or increase of pH and most of them died by change of pH by one unit. The rise of pH of water body

leads to shift of species composition from acid sensitive to acid tolerant species. Lakes suffering from acidic pH physically appeared healthy (clear and blue), but they have mostly no fish, only some acid loving mosses could be seen in these lakes. The further decline of pH lead to dissolution of toxic metals such Al^{3+} and Hg^{2+} which in normal condition remained in insoluble mineral form. Mercury also biomagnifies in food chain and accumulate in top carnivorous fishes.

The decadal mean pH of rainfall in India has shown declining trends. As per monitoring on ten global atmospheric watch stations (GAW) of India, the decadal mean pH for 1981-1990, 1991-2000, and 2001-2012 have ranged between 7.31 to 5.76, 7.45 to 4.92, and 6.16 to 4.77, respectively.[16]

Summary

The rise of greenhouse gases in atmosphere with carbon dioxide as major component is forcing more radiation towards Earth's surface which is leading to rise of average global temperature. The relationship between increase of average global temperature and increase of greenhouse gases in atmosphere depends on many feedbacks which account for the climate sensitivity of Earth, the proportionality constant between radiative forcing induced by rising greenhouse gases and change in average global. The rise of average global temperature is affecting our oceans and climate system both. The sea level is rising due to melting of irreversible melting of glaciers and ice sheets and increase of volume of oceans which is affecting 20% of human population living within 30 km of sea coast. It is not just sea level rise but is causative factor the rising CO_2 level is also acidifying our ocean which is increasing dissolution of calcium carbonate present in shell and other hard parts of marine organisms. The combined effects of heat stress and declining pH is severely affecting marine ecosystems such as coral reef ecosystems. The third impact of global warming is disturbance of thermohaline cycle (the Atlantic conveyor) which is getting slow. The unequal heating of our ocean (topical waters are heating more than other portion of oceans) due to radiative forcing is also affecting coupled ocean atmosphere cycles such as El-Nino, Madden-Julian Oscillations (MJO) etc. leading to increase of extreme oscillations of these cycles. The disturbance of coupled ocean atmosphere cycles based on tropical latitudes and their teleconnection with general circulation is increasing frequencies of adverse weather events throughout the globe. Inter Governmental Panel (IPCC) has recently calculated many shared socioeconomic pathways (SSP) with the world may follow in future with consequent rise in greenhouse gases and average global temperature. Most optimistic pathways require (SSP1-1.9 and SSP1-2.6) which requires substantial reduction of carbon dioxide emission so we achieve net zero addition till 2050. This could be achieved by carbon sequestration and capture, switching to alternative energy sources and through demand reduction. If we follow a pathway with high economic growth with increasing emission of greenhouse gases (SSP5) then only some geoengineering measures could save us from adverse impact of climate change. Some of the greenhouse gases especially halocarbons used in refrigeration, air conditioning, foamed plastics, fire retardants and industrial processes are also damaging ozone layer in stratosphere. The highly inert halocarbons accumulate in atmosphere drift in stratosphere where they release chlorine or bromine atoms which work as catalyst in destroying the ozone in stratosphere. The strong polar vortex over Antarctica creates polar stratospheric clouds which catalyze inactive chlorine species back to active chlorine gas. The photolysis of chlorine during Antarctic summer leads to creation of ozone hole. The substantial decrease of ozone concentration during 'ozone hole' cycle increases flux of harmful UV-B radiation as high as 20%. Rise of UV-B radiation (320 nm to 280 nm) is responsible for rise of skin cancers especially in countries of southern Hemisphere. It also causes ocular damage (such as cataract) and reduces human immunity. Acid rain is any rainfall with pH below 5.5. The persistent acid rain was wide spread in later half of 20th century in many industrial regions of world. Acid rain affects terrestrial ecosystems by leaching calcium from leaves and soil, and dissolving aluminum and other toxic heavy metals present as insoluble minerals in soil. Acid rain corrodes metals and alloys and destroys concrete and limestone monuments. The decrease of pH of freshwater in aquatic ecosystem also jeopardizes survival of fish and amphibians and species composition shift from acid sensitive to acid tolerant species in freshwater aquatic ecosystems.

Key words

Black body, Greenhouse effect, Global warming potential, Climate sensitivity, Radiative forcing, Ocean acidification, Sea level rise, Thermohaline cycle, Coupled ocean atmosphere circulation, El-Nino, Flood, Drought, Tropical cyclones, Shared socioeconomic pathways (SSP), Carbon sequestration and capture, UV-B, Antarctic ozone hole, Polar vortex, Skin cancer, Cataract, UV-index,

Acid precipitation, Acid deposition, pH, Metal corrosion, Concrete degradation, Nutrient leaching, Aluminum toxicity, Amphibian survival

Self Assessment

1. The average temperature of our Earth's surface depends on energy received from _____

A. Sun
B. Core of Earth
C. Space radiation
D. Both Sun and core of Earth

2. _____ of Earth works as blanket to maintain higher average temperature of Earth's surface.

A. Biosphere
B. Hydrosphere
C. Atmosphere
D. Lithosphere

3. Which of the following is the principal green house gas?

A. Nitrogen
B. Oxygen
C. Chloroflurocarbons (CFC)
D. Carbon dioxide

4. _____ provides positive feedback in global warming.

A. Cloud
B. Water vapor
C. Polar ice sheets
D. Glaciers

5. Melting of all ice sheets of Antarctica can raise ocean level to approximately _____

A. 5 m
B. 1 m
C. 1 cm
D. 55 m

6. Our oceans are acidifying due to dissolution of atmospheric _____

A. SO_2
B. CO
C. CO_2
D. N_2

7. Acidification of ocean is the cause of destruction of _____ ecosystem.

A. Coral reef
B. Lake

C. Wetland
D. Soil

8. Thermohaline cycle is a _____

A. Global movement of wind streams
B. Global movement of ocean current
C. Monsoon cycle of Earth
D. Coupled ocean atmospheres circulation

9. El Nino originates in _____ Ocean.

A. Atlantic
B. Pacific
C. Indian
D. Arabian

10. One of the strategy to mitigate climate change is:

A. Capturing of warm air from atmosphere
B. Capturing of carbon dioxide generated from human activities
C. Capturing water vapor from atmosphere
D. Increase exploitation conventional energy resources to raise GDP

11. UV radiation in _____ range is most harmful to living species.

A. UV-C
B. UV-B
C. UV-A
D. Visible

12. Which of following species work as catalyst to destroy O_3 in stratosphere?

A. O_2
B. Cl
C. O
D. H

13. Ozone hole is found over _____

A. North Pole
B. South Pole
C. Canada
D. Asia

14. The cancer type which is increasing due to depletion of ozone layer is:

A. Mouth
B. Liver
C. Skin

D. Cervical

15. A UV index of more than 11 can cause _____ in less than 10 min.

A. Fever
B. Indigestion
C. Sunburn
D. Allergy

16. Acid rain is rainfall with pH _____

A. Less than7
B. Less than 5.5
C. More than 7
D. More than 10

17. Most of the aquatic animals are adapted to survive in pH range _____

A. 1-2
B. 9-10
C. 6-8
D. 3-4

18. Which of the following acid is responsible to reduce pH of acid rain?

A. H_2CO_3
B. HF
C. CH_3COOH
D. H_2SO_4

Answers for Self Assessment

1.	A	2.	C	3.	D	4.	B	5.	D
6.	C	7.	A	8.	B	9.	B	10.	B
11.	A	12.	B	13.	B	14.	C	15.	C
16.	B	17.	C	18.	D				

Review Questions

Q1. What are the main factors which affects the average global temperature? Calculate the average surface temperature of Earth using simple black body model.

Q2. Explain the greenhouse effect. Why carbon dioxide is a green house gas, but nitrogen and oxygen are not?

Q3. How anthropogenic activities are increasing carbon dioxide in atmosphere?

Q4. Water vapor is more potent green house gas and has almost equal abundance, but we only consider carbon dioxide as principal greenhouse gas. Explain

Q5. How the future rise in greenhouse gases is linked with rise in average global temperature?

Q6. Discuss the acidification of oceans due to rising CO_2 level. How is it affecting coral reef ecosystem?

Q7. Explain the risk of rising sea level from melting of major ice sheets caused by global warming.

Q8. What is thermohaline circulation? What are the factors which power this circulation? What is its importance?

Q9. What is El Niño phenomenon? How is it linked with extreme weather events? How is it getting affected from global warming?

Q10. How global warming is affecting tropical cyclones?

Q11. Discuss the mitigation strategies to avert global warming.

Q12. What are UV radiations? How are they removed by ozone layer of stratosphere?

Q13. Why ozone hole is only created over Antarctica?

Q14. What are halocarbons which are responsible for ozone layer depletion? Where are they used?

Q15. Discuss the hazards of UV radiations. What is UV index?

Q16. Define acid rain, acid precipitation and acid deposition.

Q17. Discuss the causes of formation of acid rain.

Q18. How acid rain affects metals and building materials?

Q19. What is the impact of acid rain of aquatic species?

Q20. Discuss the impact of acid rain on plants.

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Unit 10: Environmental Laws

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Objectives

After completion of this chapter you will be able to

- know salient features of the Wildlife (Protection) Act, 1972.
- know salient features of the Forest (Conservation) Act, 1980.
- know how these Acts empower us for conservation of forests and biodiversity.
- understand salient features of Water (Prevention and Control of Pollution) Act, 1974.
- know about provisions of the Air (Prevention and Control of Pollution) Act, 1981.
- understand salient features of Environment (Protection) Act, 1986.

Introduction

We have learned the importance of natural ecosystems in providing us valuable resources and services. After independence from colonial rule, India worked towards economic development using available technologies to raise the living standard of its citizens suffering from widespread poverty. In the first decade after the formation of the Republic of India, the nation achieved sufficient industrialization especially in manufacturing, health and power sectors. However, in the coming decades the rise of population required more growth of GDP and again we utilized the available technology (now termed brown technologies) to achieve immediate economic needs like food production. Though the per capita income of our citizens got increased till the end of 1960s, but nation also suffered from decline of environmental or ecosystem services, which was evident from rise in natural calamities due to forest destruction, decline of quantity and quality of freshwater, air pollution in major cities and loss of biodiversity (like sudden near disappearance of tigers). Similar environmental degradation was also observed in other nations. This led to the UN Conference on Human Environment in Stockholm in June, 1972.

The Stockholm conference was a turning point which led India to implement two important environmental laws: Wildlife (Protection) Act, 1972 and Water (Prevention and Control of Pollution) Act, 1974. In later years, three more laws related to improvement and protection of the human environment was enacted. These are: (1) Forest (Conservation) Act, 1980, (2) Air (Prevention and Control of Pollution), 1981, (3) Environment (Protection) Act, 1986. Let us understand what salient features of these acts are, what amendments were made to strengthen these acts and how these laws empower us to enjoy a healthy environment.

10.1 Wildlife (Protection) Act, 1972

Wildlife (Protection) Act, 1972 was enacted to stop decline of keystone species (tiger, crocodile etc.) and deals with declaration of protected area as in-situ conservation method of endangered species.

Some salient features of law are:

(1) It deals with declaration of protected areas. Based on conservation and human requirements the protected area could be: National park, wildlife sanctuary (WLS), conservation reserve, or community reserve.

(2) The law establishes the administrative structure of wildlife management such as post of chief wildlife warden.

(3) It created schedules of endangered species whose hunting and exploitation are punishable as per law. All endangered animals are specified in Schedule I to IV of the Act.

(4) Protected plants are listed in Schedule VI.

2002 Amendments in Wildlife (Protection) Act, 1972

(1) The amendments made commercial use of resources in protected areas by the local community as prohibited activity.

(2) These amendments introduced the new concept of community reserve and conservation reserve where use of resources by the local community is allowed for subsistence. If the protected area is uninhabited but used by the community for subsistence then it is called conservation reserve, but when the land is used privately then these are called community reserve. The community and conservation reserves work as buffer zones or corridors between established national parks and WLS.

(3) Several definitions were altered. For example, endangered fishes were in the scheduled list of animals and forest produce were redefined to ensure complete protection of the ecosystem.

Penalties under Wildlife (Protection) Act, 1972

(1) Any offence committed to endangered species listed in Schedule I or part II of Schedule II are punishable with a penalty of 25,000 and imprisonment up to six years.

(2) Violation of any condition of license or permit given under the Act is punishable with fine of 25,000 and imprisonment up to three years.

The insufficient numbers of forest staff and lack of equipment like vehicles, weapons, radio devices etc., is one of the major causes of poor implementation of the Act.

What can an individual do?

Protection of wildlife and environment in general is the responsibility of every citizen. We can contribute a lot to the protection of wildlife. Some important actions which could be taken individually are:

(1) If you see any act of poaching of endangered species then inform forest officials at the highest possible level. The event could also be reported through the press. Follow up should also be taken for action to be taken by concerned authority.

(2) Do not buy products made from skin, or other body parts of wild animals.

(3) Try to minimize use of wood and wood products.

(4) Create organizations which can pressurize the Governments for conservation of biodiversity.

(5) Do not tease or disturb animals when visiting zoos or national park.

(6) It is good to join famed organizations like Worldwide Fund for Nature, India (WWF-India), Bombay Natural History Society (BNHS) etc.

(7) Understand the value of biodiversity surrounding your region and explain the same to your friends and family.

2002 Amendments constituted a differently structured statutory body called National Board of Wildlife (NBWL) which replaced Indian Board of Wildlife. NBWL is chaired by the Prime Minister and is an apex body to promote conservation and development of wildlife. The clearance NBWL is essential for any developmental activity in protected areas.

10.2 Forest (Conservation) Act, 1980

First law related to forest protection was implemented during the colonial era when large scale timber extraction (needed mostly for ship building and construction industry) from Indian forests causes massive deforestation. This led the British Government to enact Indian Forest Act, 1927 which created Reserved and Protected Forests. Reserved Forests were set aside to be used only by the Government, while protected forests were allowed for restricted use by locals. Scientific forestry was introduced in the Reserved and Protected Forests to maximize timber production. However, this had alienated the contribution of the local community in conservation of forests due to loss of stake and ultimately resulted in degradation and fragmentation of forests across the country.

The Second era of overexploitation and degradation of forests started after India gained independence from British rule. People thought since the British ownership of forests was transferred to their own government, so now they can use the forests in a similar way. To raise the GDP of the country forests were utilized in an unsustainable manner mainly for extraction of timber without any regard given to regulative and other services provided by the forests. The increase of natural calamities and inequalities in distribution of income generated from forest resources led to agitations in the 1970s, which finally resulted in formation of new law: Forest (Conservation) Act, 1980. The other cause of enactment of new law was massive diversion of land of Reserved Forests for non-forest use by State Governments, which decreased India's forest reserve at frightening rate. States had regularized encroachment of forest land and resettle 'Project Affected People' in de-reserved forest land. These practices urgently required new legislation to conserve forests.

Salient features of Forest (Conservation) Act, 1980

(1) No forest land could be de-reserved without prior approval of the Central Government.

(2) It provided the use of goods and services of forests by local communities for their subsistence.

(3) The law gives priority to maintenance of ecological balance and environmental stability.

(4) It clearly states that the network of protected areas should be strengthened by conserving forests.

Penalties under Forest (Conservation) Act, 1980

(1) Offences in protected forest: Felling of trees, burning of forest, cattle grazing, timber extraction etc.

(2) Penalties for offences in protected forest: Imprisonment for term up to six months and a fine up to Rs. 500/- or both.

(3) Penalty for government officials for de-reserving forest land or allowing non-forest activities in forest land: Simple imprisonment for a term extended up to 15 days.

Forest Conservation: What can an individual do?

(1) Be alert for destructive activity in green areas i.e. Reserves Forest, Protected Forest or Protected Area (national park and wildlife sanctuary). The destructive activities could be reported to the District Forest Officer, Range Forest Officer, Forest Guard or District Commissioner. Better to file an FIR. The matter could also be reported to the press.

(2) Awareness could be created in the general public about the existence and value of national parks and wildlife sanctuaries situated near your native place.

(3) If you visit a forest area then do not litter and use ecologically sensitive public transport or bicycles.

(4) Create a local organization of likeminded people and pressurize the authorities to implement forest conservation in a better way.

(5) Participate in enhancement of greenery by watering, caring and planting green plants.

Rate of diversion of forest land prior to 1980 was 1.43 lakh hectares per annum, which was reduced to 15 thousand hectare per annum after implementation of Forest (Conservation) Act, 1980. (Ref.[1])

'Protected forests' are forests which are notified as per Indian Forest Act, 1927 and where limited extraction of resources are allowed, while 'protected areas' are National Parks, Wildlife Statuaries, Conservation, and Community Reserves which notified as per Wildlife (Protection) Act, 1972, where almost no human activity are allowed. (Ref.[2])

10.3 Water (Preservation and Control of Pollution) Act, 1974

The presence of surface runoff and groundwater loops in the hydrological cycle makes it necessary that whatever pollutants which enter in water through our use (domestic, industrial and agricultural) should be carefully monitored and removed before discharge of water in water bodies. In 1974, Government of India formed an Act to provide for prevention, control and abatement of water pollution, and for maintaining or restoration of wholesomeness of water. The Act was called the Water (Preservation and Control of Pollution) Act, 1974.

Salient features of Water (Preservation and Control of Pollution) Act, 1974

(1) To fulfill the above said objective, the Act provides for the constitution of State and Central boards called State and Central Pollution Control Board.

(2) The Act provides for the constitution, powers and functions of pollution control boards.

Functions of Central Pollution Control Board (Ref.[3])

Some functions of Central Pollution Control Board are:

(1) To identify water pollutants and set safe limits for the water pollutants before their discharge in water bodies such as wetland, lake, river, sea and well.

(2) Organize a comprehensive awareness program on water pollution through mass media.

(3) To maintain cleanliness of rivers, lakes, streams and wells in the country.

(4) It advises the Central Government on any matters related to prevention and control of water pollution.

(5) It resolves disputes between State Boards and coordinates their activities.

Function of State Pollution Control Board

(1) It is responsible for inspection and collection of samples from industries, sewage treatment plants etc. and sending analysis report to respective organization

(2) To conduct research for abetment, treatment and prevention of water pollution in collaboration with the Central Pollution Control Board (CPCB).

(3) It can conduct search operations in any place where it believes that water pollution norms are violated.

(4) State board advises State Government regarding location of industry.

Penalties charges for violation of Water (Prevention and Control of Pollution) Act, 1974

The violation of industry specific standards, not furnishing information required by the Board and concealing any accident in the premises are all offences as per the Water Act. The penalties for these offences are:

(1) First violation: Imprisonment for a term up to six months or fine of Rs. 10,000/- or both and in case violation continues then Rs. 5000/- everyday.

(2) If a person who has already been convicted repeats the same offence: Imprisonment for a term not less than two years and may extend up to seven years.

Water pollution: What can an individual do?

(1) Inform pollution control board or file a complaint to their websites, if you find any offender who is polluting water.

(2) Do not dump any waste in domestic or industrial drainage which cannot be removed from effluent treatment or sewage treatment plants or can harm aquatic or human life.

(3) Use compost instead of chemical fertilizers and eco-friendly methods for paste control in your garden.

(4) Do not dump batteries and E-waste in toilets as these can corrode and can release heavy metals in water bodies.

(5) It should be understood that prevention of water pollution is better than to cure waste water and punish the offenders.

10.4 Air (Prevention and Control of Pollution) Act, 1981

Along with the spirit of the UN Conference on Human Environment to preserve quality of air, the Government of India enacted a new law in 1981 called the Air (Prevention and Control of Pollution) Act, 1981. The Act provides for prevention, abatement and control of air pollution. It conferred further powers to pollution control boards for maintaining air quality in India.

Salient features of Air (Prevention and Control of Pollution) Act, 1981

(1) Similar to the Water (Prevention and Control of Pollution) Act, 1974, the Air Act empowered State and Central Pollution control boards for prevention and control of air pollution. The boards which were only concerned with water quality before 1981 were given additional duties for air quality maintenance.

(2) The act mentions the constitution, function and powers of both the State and Central Pollution Control Board.

Function of Central Pollution Control Board (CPCB)

Some important functions of CPCB are:

(1) CPCB advises the Central Government about matters related to improvement of air quality and control and prevention of air pollution.

(2) To conduct research and set source specific emission standards for various air pollutants.

(3) To monitor ambient air quality and prepare manuals for stack gas cleaning devices.

(4) To compile and publish location specific air pollution data.

(5) To provide technical assistance and coordinate activities to the state pollution control board.

Function of State Pollution Control Board (SPCB)

Some important functions of SPCB are:

(1) SPCB advises the State Government and plans and executes a comprehensive program to control, abet and prevent air pollution.

(2) SPCB can inspect at all reasonable times, air pollution control devices, industrial plant or manufacturing processes and can give orders to concerned persons to control, and prevent air pollution.

(3) It inspects air pollution control areas and assesses the quality of air in these zones to take steps for air pollution control.

(4) SPCB can set emission standards for industrial plants, automobiles and any other source (except ship and aircraft) in accordance with standards set by CPCB.

Penalties charged for violation of air pollution norms

For violation of emission standards or contravention of any provision of Act, an industrial owner or vehicle owner can be penalized with imprisonment for a term which may extend up to three months or fine of Rs. 10,000/- or both. For continuation of violation a fine of Rs. 5000 per day (from date of first violation) could be imposed on the offender.

Air pollution: What can an individual do?

(1) When you see a polluting vehicle, note down its number and inform the Regional Transport Office (RTO) or file an online complaint with the Pollution Control Board.

(2) An online complaint could also be filed with the Pollution Control Board for an industrial unit violating air pollution norms.

(3) Avoid using fossil fuels as much as possible. Better to walk or use a bicycle.

(4) It is a better option to use public transport as more people can travel in one large vehicle which generates comparatively less air pollutants than by use of many small vehicles.

(5) Use carpooling to minimize the use of fossil fuels.

Sameer App created by CPCB (Fig. 1) could be used to track air pollution in your city and file any complaint against a person or industry that pollutes the environment.

Figure1. Pollution tracking app of Central Pollution Control Board

10.5 Environmental (Protection) Act, 1986

The full spirit of the UN Conference on Human Environment held at Stockholm in June, 1972 was incorporated in the Environmental Protection Act, 1986 which was enacted after Water and Air Acts by the Government of India. The need of Environmental Protection Act, 1986 (EPA) was realized since the four other Acts (Wildlife Protection, Forest Conservation, Water, and Air) only dealt with part of the environment. There were many inadequacies in previous laws to fully deal with any peculiar problem related to the environment such as handling of hazardous waste and substances. These inadequacies were first severely recognized during Bhopal Gas Tragedy. The Act empowers the Central Government to establish authorities to care for the environment in all its forms. The Act also empowers the Central Government to evaluate manufacturing or other commercial processes of the industries for their impact on the environment. Various Rules have been formed under this Act. These rules are related to noise pollution and waste management which are mentioned below.

Noise Pollution (Regulation and Control) Rules, 2000

To minimize the impact of ambient noise level on physical and psychological health of humans, rules specify minimum noise level in various zones called residential, commercial, and silent zones. A person can complain to the Pollution Control Board if noise level exceeds above 10 dB (A) from the prescribed limit. As per the rule written permission is required to use loud speakers and public address systems. It also prohibits use of loud speakers and public address systems at night (10 pm to 6 am).

Hazardous Waste (Management, Handling and Transboundary Movement) Rules, 2016

These rules were formed under the Environmental Protection Act, 1986. These rules specify procedure for management for hazardous and other wastes. It standardized protocols for running hazardous and other waste treatment facilities including import and export of hazardous waste. The schedule I of the rules clearly specify the hazardous waste generating industrial processes and name of hazardous substances generated from them.

Solid Waste Management Rules, 2016

Solid Waste Management Rules, 2016 is an upgraded version of Municipal Solid Waste (Management and Handling) Rules, 2000. The Rules clearly specify the duties of waste generators and duties of organizations (from ministries to local bodies to manufacturers) responsible for handling municipal solid waste. It standardizes the maintenance, and operation of sanitary landfills. It also specifies standards for composting, incineration of solid waste.

Bio-Medical Waste Management Rules, 2016

The Rules are made under EPA, 1986 to handle and dispose of bio-medical waste generated from hospitals, dispensaries, pathologies, biology labs etc. in a way which does not harm human health and environment. The Rules require the disposal of bio-medical waste as per WHO norms. It specifies duties of a common bio-medical waste management facility and immunization of workers handling bio-medical waste against prevalent infections such as Tetanus and Hepatitis B. Schedule I of the Rules clearly mention type of waste and their specific treatment process. (Ref.[4])

E-Waste Management Rules, 2016

The Rules specify the duties of Pollution Control Boards, Local Bodies in handling of E-waste. It also implements extended producer responsibility in disposal of their end-of-the-life electronic and electrical products. It specifies the limit of hazardous substances used in manufacturing of electronic and electrical products. It also specifies responsibility of consumers, recyclers, and dismantlers.

Construction and Demolition Waste Management Rules, 2016

The Rules specify duties of construction waste generators, local authorities and Pollution Control Boards. It also mentions the standards for products made from recycling of construction and demolition waste and operation of the facilities making these products. It requires that local authorities shall give appropriate incentive to generators for in-situ salvaging, processing and recycling of construction and demolition waste.

Summary

India marched towards economic development after independence from British Rule to raise living standards of its citizens utilizing available technologies resulted in degradation of the environment which was evident from pollution of major rivers, loss of biodiversity and rise of natural calamities. This provided the impetus for enactment of several laws to protect environmental services. The Wildlife (Protection) Act, 1972 and Forest (Conservation) Act, 1980 was formulated to protect natural ecosystems. Water (Prevention and Control of Pollution) Act, 1974 and Air (Prevention and Control of Pollution) Act, 1981 was enacted for control, abatement and prevention of air and water pollution. Finally, a more comprehensive law was enacted by the Government of India for protection and enhancement of the quality of the whole environment. The law was called the Environmental (Protection) Act, 1986 which removed inadequacies present in previous environmental laws. India's entry in the global economy further aggravated the problem of declining vital environmental services. The Environmental (Protection) Act, 1986 enabled the Central Government to formulate Rules under Environmental (Protection) Act, 1986 to tackle problems emerging solid waste like E-Waste, Demolition and Construction Waste, Hazardous Waste etc.

Keywords

UN Conference on Human Environment, Wildlife (Protection) Act, 1972; National Parks, Wildlife Sanctuaries, Community Reserve, Forest (Conservation) Act, 1980; Water (Prevention and Control of Pollution) Act, 1974; Air (Prevention and Control of Pollution) Act, 1981; Environmental (Protection) Act, 1986; Central Pollution Control Board, State Pollution Control Board, Noise (Regulation and Control) Rules, 2000; Hazardous Waste (Management, Handling and Transboundary Movement) Rules, 2016; Solid Waste Management Rules, 2016; Bio-Medical Waste Management Rules, 2016; E-Waste Management Rules, 2016; Construction and Demolition Waste Management Rules, 2016

Self Assessment

1. Declaration of wildlife sanctuaries and national parks are dealt in _____

A. Environmental Protection Law, 1986
B. Forest Conservation Act, 1980
C. Forest Rights Act, 2006
D. Wildlife (Protection) Act, 1972

2. Endangered plants are included in Schedule _____ of Wildlife (Protection) Act, 1972.

A. I
B. II
C. III
D. VI

3. 2002 Amendments to Wildlife (Protection) Act, 1972 _____

A. Allowed local people for commercial use of forest produce
B. Prohibited local peoples for commercial use of forest produce
C. De-recognizes rights of community over forest
D. Allowed timber extraction from forest

4. A person found guilty of hunting animal listed in Schedule I of Wildlife (Protection) Act, 1972 can be imprisoned for _____

A. 1-6 Days
B. 1-6 Months
C. 1-6 Years
D. Life

5. _____ wildlife products, we can help in strengthening the Wildlife (Protection) Act, 1972.

A. By purchasing
B. By saying no to
C. By selling
D. By processing

6. As per the _____ state government cannot de-reserve forest land for other uses.

A. Environmental Protection Law, 1986
B. Forest Conservation Act, 1980
C. Forest Rights Act, 2006
D. Wildlife (Protection) Act, 1972

7. Which of the following organization is involved in conservation of endangered species?

A. WWF-India
B. CSE (Center for Science and Environment)
C. ONGC
D. UGC

8. Felling of trees in a reserved forest is an offence as per _____

A. Environmental Protection Law, 1986
B. Forest (Conservation) Act, 1980
C. Forest Rights Act, 2006
D. LARR (Land Acquisition, Rehabilitation and Reassessment) Act, 2013

9. Hunting of endangered species is an offence as per _____

A. Environmental Protection Law, 1986
B. Forest Conservation Act, 1980
C. Forest Rights Act, 2006
D. Wildlife (Protection) Act, 1972

10. Quality of water in river and lakes are dealt in _____

A. Forest Conservation Act, 1980
B. Water Quality Act, 1974
C. Water (Prevention and Control of Pollution) Act, 1974
D. Environmental Protection Act, 1986

11. Emission standards for wastewater (before its discharge in water body) are formed by _____

A. Supreme Court of India
B. Central Pollution Control Board
C. National Green Tribunal
D. Center for Science and Environment

12. Officials of _____ can inspect any industry if there is any violation of the Water (Prevention and Control of Pollution) Act, 1974.

A. CBI
B. NIA
C. Local Police
D. State Pollution Control Board

13. Penalties charges for violation of air pollution norms is Rs. _____

A. 100
B. 10,000
C. 10
D. 500

14. _____ and pollution control board can be informed, in case you find a polluting vehicle.

A. Automobile manufacturer
B. State Transport Corporation
C. Revenue office
D. Road Transport Office (RTO)

15. Environmental Protection Act, 1986 covers areas not covered in _____

A. Forest Conservation Act, 1980

B. Air (Prevention and Control of Pollution) Act, 1981
C. Water (Prevention and Control of Pollution) Act, 1974
D. Both option (b) and (c)

16. E-Waste Rules, 2016 are formed under _____

A. Air (Prevention and Control of Pollution) Act, 1981
B. Water (Prevention and Control of Pollution) Act, 1974
C. Environmental Protection Act, 1986
D. Clean Environment Act, 1970

17. The ambient noise standards for residential, commercial and silent zones are mentioned in _____

A. Air (Prevention and Control of Pollution) Act, 1981
B. Noise Pollution (Regulation and Control) Rules, 2000
C. Noise Act, 1987
D. Wildlife (Protection) Act, 1972

18. As per the E-Waste Management Rules, 2016_____ for disposal of end-of-the-life products.

A. Electronics device manufacturer is responsible
B. Electronics device manufacturer is not responsible
C. There is no need
D. Rag pickers are responsible

19. As per the Construction and Demolition Waste Management Rules, 2016; _____for in-situ recycling of constructions and demolition waste.

A. Penalties are imposed
B. Incentive should be given
C. No incentive are given
D. None of the above

Answer for Self Assessment

1.	D	2.	D	3.	B	4.	C	5.	B
6.	B	7.	A	8.	B	9.	D	10.	C
11.	B	12.	D	13.	B	14.	D	15.	D
16.	C	17.	B	18.	A	19.	B		

Review Questions

1. Explain salient features of Wildlife (Protection) Act, 1972. How does it help in protection of endangered species?
2. What as an individual can you do to protect wildlife?
3. Even after having India Forest Act, 1927; why did we need Forest (Conservation) Act, 1980?
4. What are the salient features of the Forest (Conservation) Act, 1980? Also mention type of offences as per the Act and corresponding penalties.
5. What is the Water (Prevention and Control of Pollution) Act, 1974? Discuss function of Central and State Pollution Control Boards.
6. Write salient features of Air (Prevention and Control of Pollution) Act, 1981.
7. What as an individual can you do to prevent air pollution?
8. What as an individual can you do to prevent water pollution?
9. What was the need to enact the Environmental (Protection) Act, 1986 despite already having four Acts related to environmental degradation?
10. Discuss recently formed rules under Environmental (Protection) Act, 1986 to tackle emerging environmental pollution.

Further Reading

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Unit 11: International Agreements

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Objectives

After completion of this chapter you will be able to

- know the requirement and importance of Kyoto protocol to mitigate climate change.
- know about Montreal protocol to save ozone layer.
- understand the importance and need of Convention on Biological Diversity (CBD) to stop loss of biodiversity.
- know the importance of nature reserves of India.

- understand issues related to tribal rights and conservation of ecosystems.
- know the nature of human-wildlife conflicts in India and ways to resolve the conflicts.
- know types of solid waste and problems associated with solid waste.
- learn about integrated solid waste management (source reduction and recycling).
- understand the disposal aspect of integrated solid waste management.
- know about hazardous waste generated during various industrial processes.
- know about treatment technologies for hazardous waste.

Introduction

We have discussed (unit 9) how rise in average global temperature is increasing adverse weather events and destroying ecosystems with rich biodiversity and may massive displacement of coastal community. We have also discussed problem of rising UV index in many parts of world due to depletion of ozone layer. To save our Earth's climate and ozone layer, a combined effort by all nations of world was essential. This has led to the development of two international agreements: Kyoto protocol to stop irreversible climate change by controlling emission of greenhouse gases and Montreal protocol to stop addition of ozone depleting substances in the atmosphere. Realization of the importance of biodiversity in maintaining crucial services provided by ecosystems and as a source of massive information (which could provide solutions to our current or any future problem), led to development of another international agreement called Convention on Biological Diversity. In this unit we would learn salient features of these international laws.

Conservation efforts and resource exploitation from natural ecosystems are affecting tribal populations which are completely dependent on natural ecosystems for food, shelter, fibers etc. This unit would also talk about how collaboration of tribes in conservation and management of the natural ecosystem could enhance overall human welfare. Another problem related to nature reserves is human-wildlife conflict which would also be touched upon in this unit. Final part of the unit is about management of solid waste where best strategies for management of both municipal solid waste and hazardous waste would be discussed.

11.1 Kyoto Protocol and climate change

In order to avoid the adverse impact of global climate change, the global community met for the first time at the UN Conference on Environment and Development called Earth Summit in Rio de Janeiro in 1992. Of the five documents signed by heads of states in the conference; two important ones were: United Nations Framework Convention on Climate Change (UNFCCC) and Convention on Biological Diversity (CBD). UNFCCC was for voluntary efforts by nations, so GHG emission could be stabilized to 1990 level till the year 2000. It also established an annual forum called COP (Conference of Parties) for discussion about GHG stabilization at international level. However, five year later it was realized that instead of reduction of GHG its emission was increased by both developed and developing countries.

The failure to stabilize GHG prompted the coalition of island nations (most vulnerable nations to climate change) to call for another conference of parties to the UNFCCC. It was held in December, 1997 in Kyoto city of Japan to craft a binding agreement on reduction of GHG. On the principle of "common but differentiated responsibility" it was decided that industrialized nations would reduce their GHG emission to level about 5% below 1990 level. Thirty eight industrialized nations signed a treaty including the US to reduce their GHG emission till the year 2012. Developing countries including India and China were allowed to follow their path to development energized by fossil fuel (as was followed by developed countries) to lift millions of people above poverty.

The protocol weakened after the US withdrew from the treaty in 2001 which was followed by Canada, Japan, and Russia. With the three big GHG emitters (India, US, and China) out from the protocol, it covered control of only 13% GHG emission.

In 2007, another COP was held in Bali to decide about targets for GHG reduction after the expiration of the Kyoto Protocol in 2012. It was agreed that deep cuts are essential to avoid dangerous changes in climate. In the meeting, parties agreed to what was essentially a "road map" to future negotiations. After many conferences such as at Copenhagen (Denmark) in 2009, at Cancún (Mexico) in 2010, at Durban (South Africa) in 2011, at Doha (Qatar) in 2012, finally the

international community reached a significant global climate agreement called Paris Agreement in 2015.[1]

Paris Agreement requires all countries (low income, medium income, and high income countries) to set their emission reduction pledges (termed nationally determined contribution or NDC) so the total emission stabilizes to a level that prevent rise of future average global temperature above 2º C. Paris Agreement has replaced the Kyoto Protocol.

Did you Know?

The United States was the only country which withdrew from the Paris Agreement in 2017 under the Trump administration, but it reentered in agreement under the administration of President Joe Biden.

11.2 Montreal Protocol and ozone layer depletion

It was realized till 1974 by the efforts of scientists Molina, Rowland, (both of them got 1995 Nobel Prize in Chemistry) and Lovelock that all inert CFCs which were manufactured since the 1930s were still in the atmosphere and they could be dangerous to the atmosphere. However, after the discovery of ozone hole over Antarctica in 1985 that the nations awakened to lurking danger.

In 1987 an international meeting was convened in Montreal which led to the signing of a UN treaty called *Montreal Protocol on Substances that Deplete Ozone Layer*. The protocol called for reduction in manufacture and use of CFCs (major ozone depleting substance) by 50% till 1999. Soon it was realized that 50% reduction was not enough to save ozone layer and in 1990 a amendment was made (London Amendment, 1990) for complete phase out of all CFCs, most halons, and carbon tetrachloride by the year 2000. The Montreal Protocol is the only international agreement which was ratified by nations on Earth.

In 1991, eruption of Mount Pinatubo recorded growth of ozone hole which led to another amendment to Montreal Protocol called London Amendment, 1992 where phase out date for all CFCs was reduced to 1996. In the same year one more amendment (Copenhagen Amendment, 1992) was made which extended the ban to many more ozone depleting substances (ODS) to be phased out till 1996.

Ozone depleting substances were replaced by substances such as hydro chlorofluorocarbons (HCFC) which are degradable in the troposphere (by hydroxyl free radicals present in troposphere). The two thousand times higher global warming potential of HCHC than carbon dioxide led to the Montreal Amendment, 2007 which required complete phase out HCFC till 2030 from all countries. HFC (hydro fluorocarbons) is being used to replace HCFC.

HFC is not an ODS, however these substances have global warming potential from 12-14,000. Further, their use is increasing at a rate of 8% per year. It is estimated that till 2050, HFC would contribute to 7% to 19% CO_2 equivalent in total GHG emission (measured as CO_2 equivalent). This has led to one more amendment in Montreal Protocol in 2016 at 28th meeting of parties in Kigali (Rwanda). The amendment (called Kigali Amendment, 2016) requires 80% to 85% reduction of HFC in countries till 2040.

Montreal Protocol is one of the successful international agreements which has phased out 98% ODS globally compared to 1990 level. The impact of ODS reduction is visible by decline of Cl and Br species in the stratosphere. It is estimated that implementation of the Montreal Protocol can save 2 million people per year from skin cancer by 2030.

11.3 Convention on Biological Diversity (CBD)

Convention on Biological Diversity (CBD) is one of the five documents signed during the 1992 Earth Summit. It is a international legal instrument for:

1. Conservation of biological diversity,

2. Sustainable use of biodiversity, and

3. Equitable sharing of biodiversity.

CBD was ratified by 196 nations and ten meetings of Parties (called Conference of Parties or COP) have already been convened. The latest COP was convened in Nagoya city of Aichi Prefecture in Japan in October, 2010. The COP led to the formulation of several targets (called Aichi Targets) to be achieved in the period 2010 to 2020. The whole decade was declared as the 'UN Decade of Biodiversity'.

Some of the important "Aichi Targets" are:

1. Conservation Targets: (a) To increase terrestrial and inland protected areas by 17%.

(b) To increase marine and coastal protected areas by 10%

2. 15% of the degraded area should be restored back.

3. Special efforts should be made to protect coral reefs.

11.4 Nature reserves

Nature reserves are areas set aside for conservation of threatened plants, animals or both. Their sole purpose is conservation of ecosystem including its peculiar geomorphic features. Few examples of nature reserves are: Ranthambore National Park in Rajasthan, Periyar National Park in Kerala, National Chambal Wildlife Sanctuary in MP, and Harike Lake Wildlife Sanctuary in Punjab (Fig. 1). Nature reserves in India are recognized as national parks, wildlife sanctuaries and community reserves.

Nature reserves are important since:

1. They provide conservation of cultural and spiritual values associated with nature.
2. A lot of information value hidden in amazing biodiversity and pristine ecosystems is conserved.
3. Supply of ecosystem services remained intact due to conservation of ecosystem including crucial species which are part of the ecosystem.

(A) (B)

Figure 1: Nature reserves: (A) Ranthambore National Park, (B) National Chambal Wildlife Sanctuary (Source: The Holiday India)

11.5 Tribal rights

Tribal communities mostly live in and around forests. They totally depend on forests for food, shelter, fiber etc. Often tribal people do not have formal education. However, due to thousands year of association with forests tribal communities have good knowledge of wild plants and animals including their benefits to humans. They have also developed best practices for management of forest, for example reverence given to some trees and forest tract (called sacred groves). Lack of formal education among tribes is also a cause of ignorance among tribes about their land rights.

Tribal rights and conservation

Contrary to above fact it was assumed that presence of tribal communities in forests were deleterious to wildlife and ecosystem. In addition to the above misconception, presence of tribal

communities in forest was found to create hindrance in establishment of eco-tourism infrastructure for private and state tourism corporations. This has led to displacement of tribes from native forest homeland in the name of conservation. For example, in 2014 around 450 families of indigenous Baiga community were forcefully evicted from Kanha National Park to protect tigers. Many affected families did not receive any rehabilitation and compensation as promised by the government. Another example is Bodo tribe of which 1000 members were forcefully evicted in 2017 from Orange National Park in 2017.

Traditionally tribal communities played crucial roles in conservation, preservation and safeguarding the richness of biodiversity. Their low carbon footprint lifestyle has preserved the environment for millennia. The wisdom and traditional lifestyle of tribal communities could guide us in finding solutions to the climate change crisis. There are many examples in India where tribal communities played significant roles in conserving wildlife and forests. As an example we can consider the case of Biligirirangana Hills Tiger Reserve. The tiger reserve is also the home of indigenous tribe named 'Soliga'. However, during the creation of the reserve native tribal community was not displaced. Recent report says that the tiger population is increasing in the reserve. It is the tradition of Soliga to worship the tiger as god which helped in their conservation. The example proves that tribal people are better in looking after their forests than forest bureaucracy or anyone else.

Tribal rights and development

Economic expediency is also hurting tribal rights. To better understand this aspect let us take as an example; the conflict which occurred between the Kondh tribe of southern Odisha and mining company Vedanta.

Niyamgiri is a hill range situated in Rayagada and Kalahandi districts of Odisha. The mining company Vedanta through a joint venture with Odisha Mining Corporation (OMC) tried to source bauxite (ore for aluminum metal) from Niyamgiri Hills. Vedanta faced stiff opposition from 110 villages which are part of Niyamgiri Hills and inhabited by the Kondh tribe. It is believed by the Kondh tribe that Niyamgiri Hills is home to their god, "Niyam Raja". For the tribe development means being able to protect hills, rivers and the jungle so their god does not annoy them.

The Union Environment Ministry in 2010, cancelled the permission given to Vedanta for second stage clearance of forest as the company has not fulfilled obligations of Forest Right Act, 2006. The decision of the Ministry was challenged in the Supreme Court. The apex court ruled that permission can only be given if the consent from all gram sabhas (village councils) would have been taken as required by Forest Right Act, 2006. The whole episode has led to framing of new law protecting land rights termed Land Acquisition Rehabilitation and Resettlement Act, 2013 or LARR, 2013. LARR has replaced the old Land Acquisition Act, 1894. It increases the compensation 2-4 times the average registered sales deed and mandated social impact assessment (SIA) and consent from 80% land owner in case of private project and 70% in case of public-private partnership (PPP) project.

Tribals should be helped by the government and society by creating a market for their forest produce and by establishing necessary processing units including training them in advanced technology, so the earning of the community could be enhanced. In return the modern society can benefit from their traditional knowledge of the economic importance of wild plants and animals and from their sustainability practices.[2]

11.6 Human wildlife conflict

Another problem that we are facing in our efforts of conservation of biodiversity and enfolding ecosystems is: human wildlife conflict. As we are covering more forest area under protected area category and as the population of various regions is increasing the area where human settlement and wildlife co-occur is also increasing. We are observing conflict between human and snow leopard in Trans-Himalayan region, between human and tiger in Sunderban Delta and around Kanha National Park, and between human and elephant in Western Ghats forest region of Karnataka. A general cause of these conflicts is recurring and direct threat to the livelihood and safety of people.

Let us understand in detail what are the causes and solutions for human-tiger and human-elephant conflicts.

Human-tiger conflict

Few of the prominent causes of human-tiger conflicts are:

1. Killing of livestock: Tiger usually does not kill livestock. Most of such predation occurs when livestock enter inside protected areas or in villages (Fig. 2A) which are closer to protected areas (PAs).

2. Accidental killing of humans: Tiger rarely attacks humans. Accidental killing or mauling occurs when angry mobs try to attack tigers or during unexpected encounters with humans.

3. Men eating behavior: Although extremely rare, it has been historically documented in many parts of India that individual tigers started to recognize humans as 'prey species'. There is no scientifically proven cause of men-eating behavior of tigers. Men-eating behavior persistently exhibited by tigers of Sunderban Delta and it is believed that presence of human dead bodies in villages devastated after catastrophic cyclones facilitate conditions where tigers develop test of human flash.

Following solutions are offered to avoid conflict between human and tiger which can also help in conservation of keystone species of forests and grasslands.

1. Capture and removal of problem tigers.

2. Creation of fencing or aversive conditions to stop entry of tigers in human settlements.

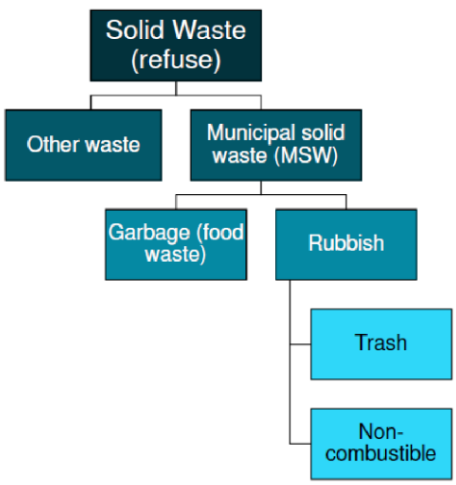
3. Timely payment of compensation to families who have suffered from loss of their loved ones.

4. Relocation of human settlement from areas which are part of the tiger corridor.

11.7 Human-elephant conflict

Human-elephant conflict is significant as it causes high economic losses and is also responsible for high human fatalities. In 2010, as per data of Ministry of Environment and Forest (MOEF) 400 people were killed in elephant related conflicts and some 5,00,000 families got affected due to damage of their crops especially staple crops attacked by elephants. Around 100 elephants were also killed in retaliatory attacks by farmers. In Karnataka itself which has a high density of elephants, 91 people were killed and 101 elephants died in the period 2008-2011.[3] In most of the cases poor recognition of ecological boundaries of PAs meant for elephant conservation, encroachment of wildlife corridors used by elephants, and lack of food in their habitat lead to human-elephant conflicts (Fig. 2B).

Human-wildlife conflicts severely affect conservation efforts. It is essential that all the causes leading to conflict should be removed scientifically. For example, the boundary of protected areas should be determined ecologically, instead of fixed arbitrarily. Human settlement should be



relocated from the wildlife corridors used by tigers or elephants. Residents of villages situated at the boundaries of PAs should be given knowledge about animal behavior and value of conservation. Traditional knowledge of tribal communities (such as Soliga of south India) could be utilized to avoid the conflicts and enhance ecosystem services.

(A) (B)

Figure 2: Human-wildlife conflict: (A) Human-tiger conflict, (B) Human-elephant conflict.

11.8 Solid waste: Classification

All the solid materials generated during domestic and industrial activities which we consider useless and end of the life products are termed as solid waste. 'Refuse' is another term that is used to describe solid waste materials, but solid waste is the preferred term. Two major categories of solid waste are:

1. Nonhazardous waste

2. Hazardous waste

Nonhazardous waste is further subdivided in two classes: 1. municipal solid waste, 2. other waste (Fig. 3).

Figure 3: Classification of nonhazardous waste. Municipal solid waste (MSW) is waste which is collected by the municipality from households, commercial establishments for their disposal and treatment. MSW is further subdivided in garbage and rubbish. Garbage is composed of food waste which could be easily decomposed by microbes and converted to compost. Rubbish is solid waste which cannot be easily degraded by microbial processes. Rubbish is composed of combustible material called trash and noncombustible solid waste. Trash can be disposed of by combustion in incinerators.

Other waste refers to solid waste which is not collected and disposed of by municipalities. Following solid wastes comes under this category.

1. Construction and demolition waste

2. Industrial nonhazardous waste

3. Mining waste

4. Agricultural waste

5. Municipal sludge

6. Auto bodies

7. Trees and bushes (coming from land use change)

Municipal solid waste constitutes only around 2% of total solid waste generated in a country and 98% are other waste. However, the majority of other waste is actually generated in producing goods needed by households which finally end up in municipal waste streams.

Case Study: Wariana landfill, Jalandhar

Jalandhar city of Punjab generates 350 TPD (tons per day) of municipal solid waste. All the waste is dumped at landfill (Wariana landfill) situated near village; Wariana. Landfill is made of growing mountains of around 8 lakh metric tons of garbage (Fig. 4). The landfill is about to saturate.

Groundwater has been contaminated due to landfill and the majority of poor residents (mostly migrant workers) living around Wariana have been suffering from water borne diseases such as typhoid. In response to demand (to remove unsightly landfill) of citizens residing in nearby localities, Jalandhar Municipal Corporation then made a plan to install a waste to energy plant to get rid of mountains of garbage.

The proposed waste to energy plant (WTE) was opposed by local residents as it is associated with increasing air pollution in the surrounding area.[4] The combustion of solid waste generates toxic particulates and volatiles which can escape from flue gas scrubber (vide supra) of WTE plant. The example shows the problem associated with disposal of municipal solid waste. Let's learn what are the best methods of management of solid waste.

Figure 4: Wariana landfill, Jalandhar, Punjab. (Source: The Tribune)

Other waste: Some examples

Before learning about integrated solid waste management, let us discuss some examples of other waste.

11.9 Mining waste

To obtain the minerals that our society needs requires a large amount of earth- and ore-removing. Mining of minerals is performed by digging holes, removing the ores and in the process the pile up of large amounts of leftover residues creates enormous aesthetic, environmental, economic and energy problems (Fig. 5). Table 1 shows the typical amount ore required to produce 100 kg of some important metals and associated waste generation.

Figure 5: Massive earth removal and leftover generation in mining.

11.10 Industrial waste

Extraction of metal from ore generates a further amount of waste. On average production of 100 kg of metal generates around 1 ton of waste material (Table 1). The extraction of metals requires a considerable amount of energy which has its own environmental impact. For some materials such as aluminum, the cost of energy constitutes a major fraction of total cost of production of material. In these cases recycling is often a better option than production of virgin material. Use of processed materials in production of the final product further generates more waste.

Table 1: Amount of ore needed and waste generated in generation of 100 kg of metals (Ref. [5])

Metal	Average Grade (%) of Mineral	Ore (kg)	Product (kg)	Residue (kg)
Al	23	435	100	335
Cu	0.91	10,990	100	10,890
Fe	40	250	100	150
Ni	2.5	4000	100	3,900
Others (avg.)	8.1	1234	100	1,134

Did you know?

Consuming less not only reduces the generation of MSW, but it also reduces energy, material and waste (mining and industrial) associated with its manufacturing. So, we need to think about a complete set of processes that result in products required by our society to tackle the problem of solid waste.

11.11 Integrated solid waste management

Integrated solid waste management deals with aspect of generation of waste, recycling of materials, and ultimate disposal of remaining waste. The various steps involved in integrated solid waste management in order of priority (highest at top of the table and lowest at the bottom of the table) are explained in Table 2.

Table 2. Integrated solid waste management (Source: Ref. 5)

Source reduction

- Reduce toxicity
- Less packaging
- Product reuse
- More durable product
- On-site mulching and composting

Recycling

- Collecting
- Processing
- Use of recycled materials in products
- Composting

Disposal

- Combustion with energy recovery

- Landfill
- Incineration without energy recovery

Source reduction and recycling is given highest priority in almost all circumstances. Following point can explain the reasons behind it.

- It reduces the waste which is to be burned or land filled.
- The pollution associated with mining (material extraction), manufacturing of product, and disposal of waste.
- It helps in conservation of precious resources.

Now let us learn about the three important aspects of solid waste management (source reduction, recycling, and disposal) in more detail.

Source reduction

Source reduction is based on a simple principle: "Garbage that has not been produced, need not to be collected". The goal of source reduction could be achieved by green product design, lifecycle assessment of products and eco-labeling of these products for enabling consumer decision.

11.12 Green product design

The design which takes into account environmental impact of manufacturing, use, and disposal of the product is termed green design. Green products are gaining more and more acceptance with consumers as we are becoming more concerned about the quality of the environment. Following points are considered in green design strategy.

Material selection and reduction of material intensiveness: The materials needed for making a product should be selected in a way that environmental impact during material extraction, processing, and its retirement could be minimized. Amount of material needed in making the product should also be minimized. Current advancement of material science provided the designer a lot of light weight composites, ceramics and advanced alloys which can provide the same strength and resilience which needs more weight metal or alloys. For example, in the 1950s telecommunication c cables were made of copper metal insulated with lead, in the mid-1980s heavier lead was replaced with lighter polyethylene and recently these are being replaced with optical fiber cables. Optical fiber cables weigh 3% of old copper cables and need just 5% of energy to produce. Further, selected material should also be non toxic in nature. The use of toxic volatiles and heavy metals should be avoided in making of product.

Product life extension: Products should be designed which are durable, reliable, reusable, repairable, and remanufacturable (vide supra). This minimizes the amount of solid waste needed to be disposed off.

Material life extension: Green design requires that almost every part of the product whether a vehicle or electronic gadget should be recycled. In Europe, laws such as *End of life Vehicle* or ELV Directive and *Waste Electrical and Electronic Equipment* (WEEE) Directive require extended manufacturer responsibility to take back their end of life products and recycle or remanufacture them with minimum impact on the environment. In India, Electronic Waste Management Rules, 2016 also impose extended manufacturer responsibility in recycling, remanufacturing and disposing of the end of life electrical and electronic products. These laws specify a minimum percentage of components to be recycled including capping the amount of toxic substances used in their manufacture.

Process management: Process management is concerned with increasing efficiency in energy and materials utilization in manufacturing of a given product. Energy efficiency could be achieved by increasing power consumption efficiency of electric motors used for running robotic arms, conveyor belts, drilling machines etc. Since electric motors account for two-thirds of electricity used by industry, it could be a good place for looking at efficiency. By utilizing waste heat, fuel consumption efficiency could also be increased. Material efficiency could be achieved by pre-estimating (and ordering accordingly) the needed input, and by more careful inventory control.

Efficient distribution: The distribution of products to consumers could be made efficient by judiciously deciding about packaging and mode of transportation. Packing should be kept at

minimum so the quality of product could be maintained and it should be made of recyclable material as much as possible. Route of transportation depends on cost of transportation and time needed for delivery of product to market. Shipping by boat is the cheapest transportation as per kilometer cost which is followed by rail, truck, and then air. Shipping by air is the fastest mode of transportation but requires the highest energy per ton-mile travelled. For the same mode of transportation, cost depends on the terrain of the region where products are needed. Further, by strategically locating manufacturing facilities a lot of cost (and associated environmental impact) on packaging and transportation (of products) could be reduced.

11.13 Eco-labels

To promote green products made by maximum consideration all above aspects could be promoted in market by life cycle assessment (LCA) of given product in terms emission, energy input, and disposal impact. A comparative analysis could help consumers in conserving resources, and in maintaining environmental quality. However, use of terms like "eco-safe," "ozone friendly," "biodegradable," "recyclable" by manufacturer to promote their products are vague in nature and does not provide any effective assessment of environmental impact of products. Terms like "eco-safe" are largely undefined and since ozone depleting substances are already banned so writing "ozone friendly" on a product is of no meaning. A credible labeling system removing ambiguity about environmental standards satisfied in assembly of product could be a powerful motivator in market place. This is fulfilled by the development of national certification system in many countries such as "Blue Angel" label given to eco-friendly products in Germany and "EcoMark" given to products by the Bureau of Indian Standards (BIS) in India. These certifications consider many aspects such as impact of product on public health and environment, use of renewable energy and efficiency, use of recycled materials, corporate environmental and social responsibility, and end of life management for sustainable reuse of materials.

11.14 Lifecycle assessment

Lifecycle assessment (LCA) is a new broader approach to the problem of solid waste management. In the LCA approach, we try to optimize both energy and material used at every stage of the product lifecycle. LCA helps us in comparing the environmental impact of two products having the same application and in designing better products. A conceptual diagram of lifecycle assessment of a product is given in Figure 6.

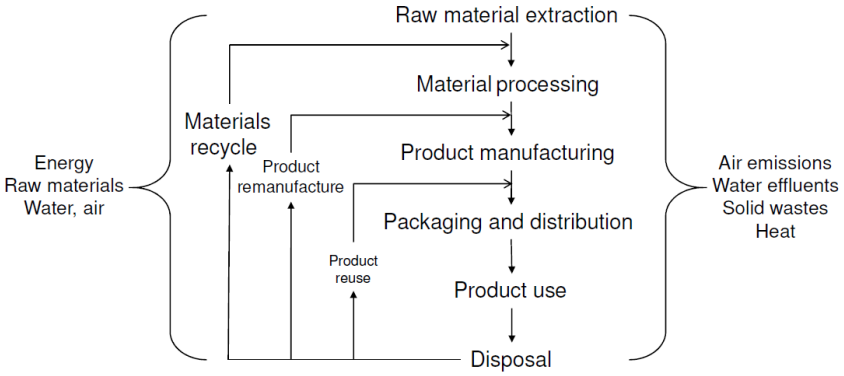


Figure 6: Lifecycle of a product.

As explained in the figure, the whole lifecycle of a product is associated with energy and material input almost at every stage from production, use, and disposal of product. Central portion of the diagram depicts various stages of the product lifecycle, which includes material extraction, material processing, actual manufacturing of product, packaging and distribution of the product, use of the product, and final disposal of product. The outputs are emission of air and water pollutants, generation of solid waste including waste heat dissipated in the environment plus energy that may be recovered during disposal.

Reusing products for the same application again and again instead of using them one time is originally intended to save energy and resources. For example, use of glass bottles for refilling soft drinks. The use of plastic grocery bags multiple times for carrying groceries home from market instead of disposing it after single use, is another example of reuse of product.

Remanufacturing of a product refers to restoring the product to a new like condition. In remanufacturing the whole product is disassembled and reusable parts are cleaned and refurbished. The refurbished components along with new components are used in assembling the product again. Remanufacturing is different from repair as in repair only the faulty component is replaced with a new component. *Recycling* is a term which is used for recovery of material from waste stream and its further processing so they can be used in manufacturing of various products. Figure 6 explains how resorting to reuse, remanufacturing, and recycling can reduce emission of pollutants and generation of solid waste.

11.15 Recycling

After source reduction (by applying green design strategy), the second most priority in integrated solid waste management is given to recycling and composting. Resource recovery is important as it reduces pressure of mining on our natural ecosystems especially biodiversity rich forests. There are many materials which are used in assembly of different products that can be recycled. We can recycle papers, cardboards, metals, alloys, plastic, rubber, food waste etc. Let us understand recycling by taking examples of recycling of plastic and construction and demolition waste.

11.16 Recycling of plastic

Plastics are polymers which are made from polymerization of small hydrocarbon and hydrocarbon derivatives mostly obtained from crude oil. Plastics are classified in two major categories: *thermoplastics* and thermoset plastics. The products formulated from plastics are labeled by various numbers enclosed under a triangular arrow, so users can recognize the type of plastic (Fig. 7). The coding also helps in segregation of plastic waste plastic products according to type of material used.

Figure 7: Labeling system of polymers used in different products (LDPE: Low density polyethylene, PS: Polystyrene, for others see text).

High density polyethylene (HDPE) and polyethylene terephthalate (PET) are the most recycled plastics. PET (given symbol 1, Fig. 7) is used to store carbonated beverages and food items where we want to preserve the aroma of food. The PET bottles are easily converted to fibers which are used for the manufacturing of winter jackets and blankets. Recycled PET plastic is also used for making food containers but the inner and outer surfaces are made from virgin PET as harmful chemicals may penetrate inside solid plastic. Mostly, recycled plastic is used for making detergent bottles, trash can and drainage pipes.

Though thermoplastics could easily be melted and reformulated in different objects. But if one plastic is mixed with other plastic material, the properties of recycled material change drastically which can make it useless for manufacture of the product. A single bottle made of polyvinyl chloride (PVC, symbol 3, Fig. 7) in 20,000 bottles (made of HDPE) can destroy characteristics and desired properties of HDPE. Mixtures of plastics could be used in making lumber which could be used in regions scarce of timber. Plastics can also be disposed off by burning it in an incinerator. But some plastics such as PVC combustion generate toxic and corrosive hydrochloric acid (HCl). PVC also creates contamination problems in recycling of other plastics. However, recent development of chlorine atom recognizing sensors and air jet based mechanical separators have made segregation of plastic quite easy. Sorting of recyclable materials is very important to get high

grade recycled materials. It could be done at the consumer, by the crew of the collection facility and finally at automated material recovery facilities (MRF). MRF use advancement in sensor technology and mechanical engineering (such as use of air knife) to precisely segregate the commingled waste materials (Fig. 8). The sorted materials are densified and sold back to processing and manufacturing industries.

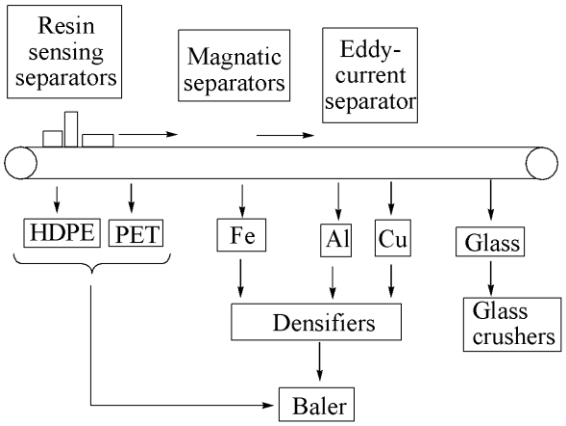


Figure 8: Functioning of material recovery facility (MRF).

11.17 Recycling of construction and demolition debris

Construction and demolition (C&D) debris is generated during renovation or demolition of residential and non-residential buildings. It includes debris from residential and non-residential building sites such as wood, metals, gypsum, wall boards, roofing, concrete, asphalt. Often it includes trees, stumps, earth and rocks generated from clearance of land for construction sites. Most of C&D debris comes during renovation of residential buildings and demolition of non-residential buildings.

Majority of C&D waste is relatively clean, unmixed and non-hazardous materials and 95% of it could be recycled. However, generally 25% of the C&D waste is generally recycled and rest is sent to landfill. Land filling of C&D debris does not have any harmful effect on the quality of water and soil. Current emphasis of green or eco-housing is changing the scenario in recycling of C&D debris. The US Green Building Council has created a rating system called *Leadership for Energy and Environmental Design* (popularly known as LEED) where more emphasis is given for recycling of C&D waste. In one parameter of their rating system 1 point is given for 50% recycling, 2 for 75% recycling, and 3 for 90% recycling of C&D waste.

11.18 Composting

Composting is a natural degradation process (aerobic degradation) of bio-waste where the conditions are controlled to shorten composting time, to minimize space required for composting and to minimize offensive odors. The product composting is a marketable soil conditioner which is also called mulch. Mulch is a fine soil amendment, but concentration of essential nutrients (N, P, K) in mulch typically remains low to compete with commercial fertilizers.

Simplest composting system is made of windrows with a typical height of 2m, width of 3-4m, and length 10-20 m. Parameters affecting composting are: temperature, pH, nutrient level, and oxygen.

Temperature. Composting is initiated by mesophile microbes which thrive within a temperature range of 25ºC to 45ºC. The continued decomposition by mesophiles increases the temperature of windrows. As temperature increases above 45ºC, activity of mesophiles stops and thermophilic microbes take over the task of decomposition. The prevalence of temperature above 55ºC for 72h inside the windrow can destroy all pathogens including seeds of weeds thus providing harmless compost. With a drop of nutrient level microorganisms die off and temperature reaches to ambient level.

pH. Early stage of decomposition generates acids with consequent decline of pH. The decrease of pH below 5 creates conditions favorable for acid tolerant fungus. Eventually, microorganisms also break down organic acids and pH again reaches normal level.

Nutrient level. The growth of microorganisms depends on the carbon to nitrogen ratio (C/N ratio) of initial bio-waste used to make compost. The ideal C/N ratio for microbial growth is 25 to 35.

High C/N ratio inhibits microbial growth, while low C/N ratio accelerates rate of decomposition, but may cause loss of nitrogen as ammonia (NH_3) and also depletes level of oxygen in windrows leading to foul-smelling anaerobic conditions. Leaves, cornstalks, rice husk, and paper all possess high C/N ratio. Grass clippings and sewage sludge have low C/N ratio. Proper mixing of different kinds of bio-waste can provide an ideal C/N ratio for fast, odorless composting. For example, high nitrogen and moisture containing sewage sludge is a nice complement for municipal solid waste (low in nitrogen and moisture).

Oxygen. As aerobic microbes degrade bio-waste, the oxygen level of windrows decreases. The deficiency could be fulfilled by mixing or turning windrows or by forced ventilation, so maintain an odorless high rate of composting.

Disposal

After source reduction and recovery of recyclable material from the waste stream, we can dispose of remaining waste either by burning in an incinerator with or without recovery of heat or by burying it in landfill. Let us learn about both of these options.

11.19 Incineration

Incineration of waste, especially municipal solid waste (MSW) has a number of favorable attributes. These include: (1) volume reduction, (2) immediate disposal (without waiting for slow biological processes to do the job), (3) less requirement of land area, (4) destruction of hazardous waste, (5) recovery of useful energy. Figure 9 shows the functioning of typical incinerator coupled with energy production (waste to energy or WTE power plant).

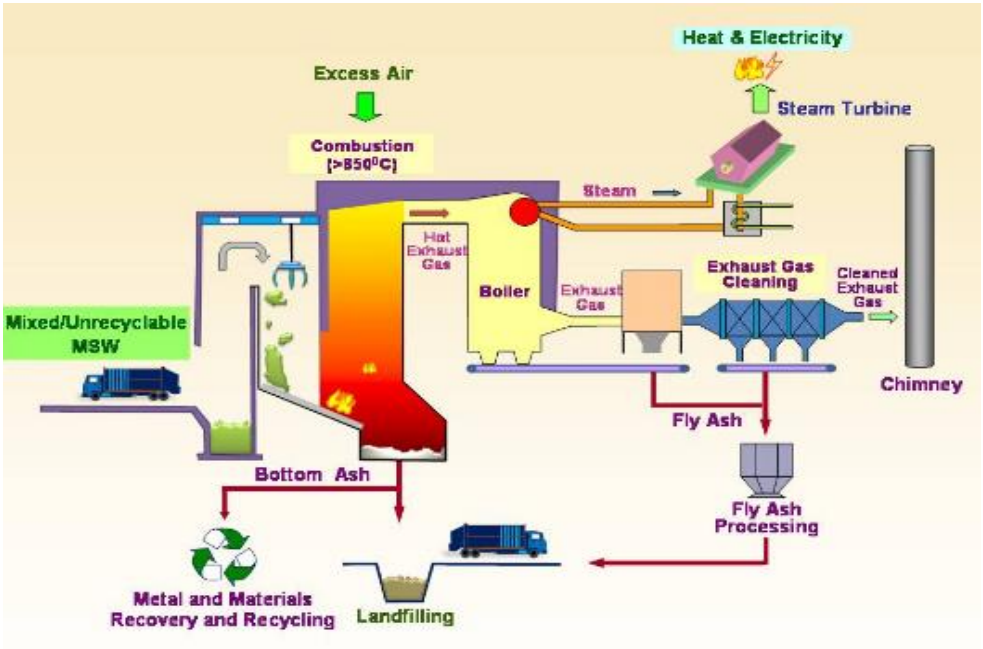


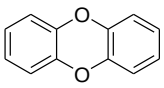
Figure 9: Typical waste to energy power plants. (Source: EPA, US)

Environmental impact of poorly operated incinerators like release of toxic substances in exhaust gases and generation of hazardous ash is a major cause of opposition in the general public about the technology (see the case study on Wariana landfill) if incinerators are going to be installed in their own area. Concern between recycling and incineration is another hurdle impacting popularization of WTE plants as development of new or better recycling technology may affect supply of waste to plants. As environmental impact is a major hurdle in the installation of incinerators, let us discuss the environmental impact of incinerators in detail and how it could be minimized.

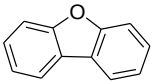
Environmental impact of WTE

Since combustion is involved in incineration, generation of ash and major air pollutants (NOx, SOx, CO etc.) associated with combustion of fuel and biomass are also formed in incineration of waste. However, pollutants which especially concern us are: polychlorinated biphenyl (PCB), dioxins, furans, heavy metals and polyaromatic hydrocarbons (PAH).

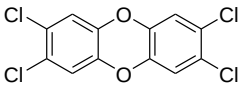
Dioxins and furans. Dioxin and furan are common terms used for various derivatives of dibenzodioxin and dibenzofuran (Fig. 10). Total 76 derivatives of dioxin and 136 derivatives of furans have been recognized. The most common and most toxic of them is: 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (2,3,7,8-TCDD). It is a known human carcinogen with no safe dose. Dioxins also cause reproductive, developmental (since they confuse biological signaling), and immune system problems in birds, fish, and mammals. There is serious concern over the impact of dioxins on human fetus development. Dioxins also accumulate in the food chain contaminating pork, dairy, and poultry products including fish.



Dioxins



Furans



2,3,7,8-tetrachlorodibenzo-*p*-dioxin or 2,3,7,8-TCDD

Figure 10: Structures of benzo fused analogues of dioxin and furans and one of its derivatives.

Combustion at temperature 900ºC with residence time 1-2 seconds substantially reduces emission of dioxins. If dioxin precursors such as HCl, phenols, chlorophenols, and aromatic hydrocarbons are not destroyed then they react in the presence of fly ash (working as surface catalyst) creating new derivatives of furans and dioxin exiting with flue gases coming out from smoke stack of incinerator.

Heavy metals. Metals such as Pb, Zn, Cd and Hg are typically part of MSW, so when burned it becomes the part of gases and particulates that leave the combustion chamber or becomes the part of ash residue. When metal containing waste is burned in an incinerator metal evaporates and becomes part of flue gas. Cooling of flue gas condenses metal and then mostly adsorbs on particulate matter (PM) of size below 2 μm. Hence, most metal can best be removed from incinerator emission by cooling flue gases below condensation temperature of most gases and by efficient removal of particulate matter. In metals (which part of wastestream), mercury removal is especially problematic since it has very low condensation temperature. It can best be removed by avoiding mercury containing products (battery, fluorescent lamp, and thermometer) to be deposed as MSW.

MSW incinerator ash. Incinerator ash is generated in two forms: fly ash (airborne particulates) and bottom ash. Both of which remained contaminated with dioxins and heavy metals. There are two dangers associated with incinerator ash. Since fly ash can easily become airborne, it has the danger of being inhaled and ingested. Second, if it is disposed of in landfill then acidic conditions can dissolve metal present in ash in the leachate of landfill. Movement of leachate causes pollution of soil and groundwater. A better option of removal of metal from incinerator emissions is removal of metal from waste stream at source or at material recovery facilities especially in areas where waste is disposed through incineration.

11.20 Landfills

As we think about landfill, a site of a local dump infested with flies, rats, odor, airborne bits of paper and garbage, and clouds of black smoke comes to our mind. This is the major reason for opposition to construction of a new landfill site by the general public if it is constructed in their locality. However, modern scientifically designed landfill does not create any such problem. Let us discuss construction and function of modern landfill.

Basic construction and function of landfill

Two major problems associated with landfill are generation of flammable and odorous gases and liquid leachate. A modern landfill successfully addresses the above two problems. To avoid leachate problems, they have a composite liner and liquid collection system at their bottom. Composite liner consists of flexible membrane liner (FML) placed on compacted bottom soil. The leachate is collected by perforated pipes situated above FML.

Operation of landfill works around three aspects: *cell*, *daily cover*, and *lifts*. Waste is compacted after being received and soil (or other material) cover is laid over compacted waste (termed 'cell') at end of the day ('daily cover') to prevent windblown spread of refuse, control of odor, and to control amount of water entering the cell. When a given area is filled with cells, another layer called 'lift' is added on the top (Fig. 11).

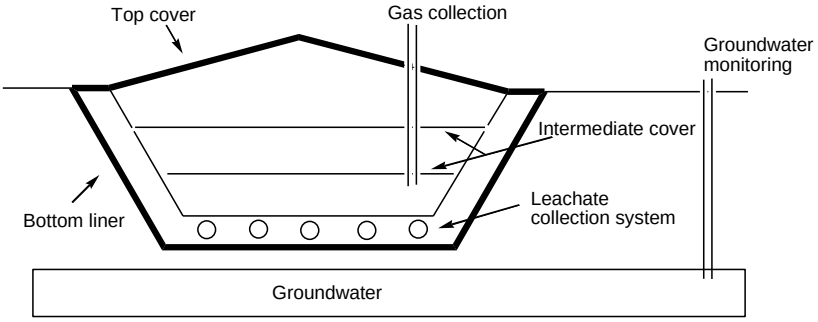


Figure 11: Construction of a modern landfill.

In landfill decomposition occurs in four phase:

Phase I: Aerobic digestion which lead to fast decline of oxygen inside cell,

Phase II: Acidogenesis caused by anaerobic decomposition generating organic acids (acetic acid as major component),

Phase III: Unsteady methanogenesis where percent of methane increases in gases generated during decomposition,

Phase IV: Steady methanogenesis where percent of methane stabilizes in gases liberated by landfill.

However, as moisture content of landfill discard decreases, rate of also decreases reaching to almost zero value after a few years. This way landfills present a good option for carbon storage. Methane production can also be enhanced by recirculating leachate through landfill mass. The generated methane after cleaning (removal of corrosive volatiles and gases) could be utilized as fuel for power generation and domestic use. Methane is collected by a system of perforated pipes penetrating gravel cover beneath the impermeable cover laid over the upper surface of landfill (Fig. 11). Management of municipal solid waste (MSW) through the 'integrated solid waste management' concept (source reduction, recycle, and disposal) is explained in Figure 12.

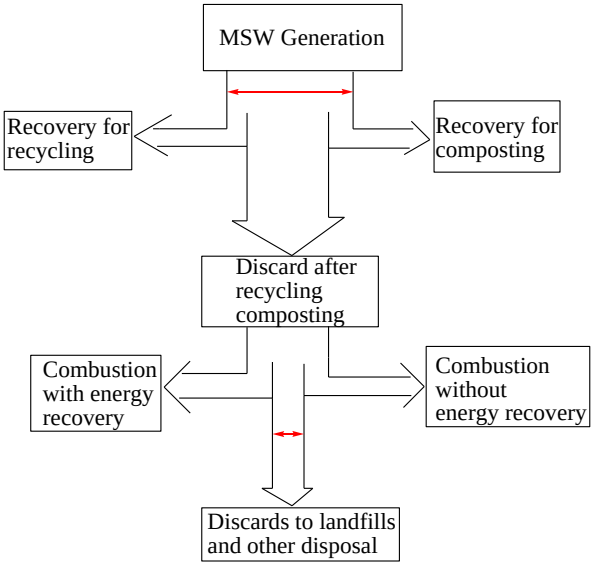


Figure 12: Integrated solid waste management of MSW. Red arrow in upper and lower portions explains how much volume of waste is reduced before reaching to final disposal.

11.21 Hazardous waste

Till now we have discussed management of nonhazardous waste which mostly does not pose any harm to humans. Hazardous wastes are wastes which are: (1) Ignitable such as waste hydrocarbon solvents, (2) Corrosive such as HCl, HF, NaOH, (3) Reactive such as chlorine, pyrophoric substances (e.g. metal hydride), (4) Toxic such as organophosphates pesticides, (5) Infectious such as hospital waste, (6) Radioactive such spent fuel rods. Hazardous waste is mostly generated in industrial operations. Table 3 lists the names of industrial processes and specific hazardous waste (as listed in Hazardous Waste Management Rules, 2016) generated by them.

Table 3: List of industrial processes and associated hazardous waste

Processes	**Hazardous waste**
Petroleum refining	Oil sludge, Spent catalyst, Slop oil, Organic residue, Spent clay containing oil
Hardening of steel	Cyanide-, nitrite- containing sludge, Spent hardening salt
Production of plastics	Spent catalysts, Process residues
Production or industrial use of synthetic dyes	Residues containing acid, toxic metals, organic compounds
Pulp and Paper Industry	Spent chemicals Strong acid and bases Absorbable organic halides(AO_X)
Electronic Industry	Process residue and wastes, Spent etching chemicals and solvents
Pharmaceutical Industry	Spent catalyst, Spent carbon, Date-expired products, Spent solvents
Pesticides industry	Sludge containing residual pesticides, Spent solvents, Spent catalysts, Spent acids

11.22 Hazardous waste management

For management of hazardous waste priorities are set in following order:

1. Source reduction,

2. Reduce generation,

3. Recycle/reuse,

4. Treatment,

5. Disposal

In case of hazardous waste, source reduction is given first priority. We have to design a product or process in a way which does not require use of hazardous substances. If these are no options then at least we should minimize use of hazardous substances which can reduce the generation of hazardous waste. In case of we use hazardous waste in a process or product and all of it should be recycled and reused. If recycling and reuse is uneconomical then we have to treat hazardous waste so it could be converted to nonhazardous end products. The disposal of hazardous waste is given last priority.

The treatment methods of hazardous waste are classified in four categories: physical treatment, chemical treatment, biological treatment, and waste incineration. Land disposal is given last priority for treatment of hazardous waste. For details about treatment technologies used for hazardous waste readers are referred to reference five.

Summary

World community united for the first time to avoid dangerous anthropogenic interference with the climate system caused by the rise of GHG gases for the first time in 1997 at a UN called meeting on climate change held at Kyoto, Japan in 1997. This meeting led to the famous Kyoto Protocol, 1997 on control of global addition of GHG in the atmosphere. Though three big emitters (US, China, India) walked out from the Protocol, after comprehensive negotiation started at the Conference of Parties (COP) meeting held in Copenhagen in 2009 and lasted till COP held in Doha in 2012, finally led to the recent Paris Agreement, 2015. Another problem caused by some selective GHG (CFCs, halons etc.) is decline of ozone layer protection. The problem of ozone layer depletion is dealt with in another UN treaty called Montreal Protocol, 1987 which is ratified by almost all nations of the world. The Montreal Protocol is a good example on how joint efforts by all nations of the world can solve a global problem. The decline of biodiversity is dealt with in another international agreement called Convention on Biological Diversity (CBD) signed along with UN Framework Convention on Climate Change (UNFCCC, Kyoto Protocol was outcome COP who signed UNFCCC) at the Earth Summit held in Rio-de-Janeiro in 1992. The effort to save biodiversity has one bad consequence due to the misconception that human intervention is not good for conservation of endangered species. This has led to displacement of many tribes from their native forests which have been their home for millennia. Tribals are also displaced from their native forests due to development activities since many forests are also sites of rich mineral deposits. Since tribes know in a much better way the value of forest, they should be made part of conservation, eco-tourism, and developmental efforts. Management of solid waste needs integrated efforts which require minimization of causes of waste generation from product design to disposal of end-of-life products. The combination of current technologies and active participation of common people is required to resolve not only the problem of solid waste, but also can conserve our renewable and nonrenewable resources.

Keywords

Environmental ethics, Human virtues, Anthropocentrism, Enlightened anthropocentrism, Intrinsic value, Intra-generational equity, Intergenerational equity, Gender equality, Gandhian way of life, Hindu philosophy of 'Karma', Asceticism, Sustainability, Indian mythology, Venerated trees and plants, Vehicle of god and goddess, Sacred groves, Environmental communication, Psychology of target audience, Effective messaging, Environmental education, Shantiniketan model

Self Assessment

1._____ is an international accord to stop climate change.

A. Montreal Protocol
B. Convention on Biological Diversity
C. Kyoto protocol
D. Shimla Accord

2._____ was an accord to reduce the level of CO_2 below 5% of the level of CO_2 in 1990.

A. Kyoto Protocol
B. Paris Agreement
C. Montreal Protocol
D. Doha Convention

3. The Kyoto protocol to stop climate change was replaced by _____ in 2015.

A. UN Accord
B. Paris Agreement
C. Montreal Protocol
D. Doha Convention

4. Montreal protocol is an international agreement to phase out _____

A. CO_2 generating processes
B. SO_2 generating processes
C. Ozone depleting substances
D. Plastic

5._____ of Montreal Protocol requires gradual reduction of HFC.

A. London Amendment, 1992
B. Montreal Amendment, 1997
C. Kigali Amendment, 2000
D. Kigali Amendment, 2016

6. Convention on Biological Diversity is an international instrument for _____

A. Conservation of biological diversity
B. Sustainable use of biological diversity
C. Exclusive rights of a nation on its endemic biodiversity
D. Both conservation and sustainable use of biodiversity

7. Aichi Biodiversity Targets are recently decided in COP (Conference of Parties) of nations which ratified _____

A. Paris Agreement
B. Kyoto Protocol
C. Convention on Biological Diversity
D. Montreal Protocol

8. Nature reserves are protected areas whose sole purpose is _____

A. The protection of mining industries
B. The protection of mineral reserve
C. The protection of nature
D. The protection historical monuments

9. The cause of conflict between tribal rights and conservation was _____

A. Thinking that tribal presence is deleterious to conserve endangered species
B. Tribal customs
C. Illiteracy of tribal
D. Tribal criminality

10. Vedanta's Niyamgiri Hill project resulted in conflict between tribal and Vedanta group over_____ in Niyamgiri hills.

A. Copper mining
B. Gold mining
C. Iron mining
D. Bauxite mining

11. _____ is one of the reasons for human tiger conflict.

A. Destruction of crops
B. Beauty of tiger
C. Animal eating behavior
D. Men eating behavior

12. Two major categories of nonhazardous solid waste are _____ and other waste.

A. Construction & demolition waste
B. Trash
C. Municipal solid waste (MSW)
D. Mining waste

13. Production of 100 kg of a metal generates on average approximately _____ kg of mining waste.

A. 1
B. 10
C. 100
D. 1000

14. Reduction of _____ is an important aspect of Green Design.

A. Production
B. Demand
C. Material intensiveness
D. Quality

15. For fast and odorless composting of garbage maintenance of sufficient _____ is essential.

A. Oxygen
B. Carbon dioxide
C. pH
D. Both pH and oxygen

16. Municipal Solid Waste (MSW) after recovery of recyclable and compostable materials is sent to _____ for volume reduction.

A. Landfill
B. Sludge treatment plant
C. Waste to energy incinerator
D. Industrial boilers

17. To stop contamination of groundwater from landfill site, we provide bottom liner and _____ in modern landfills.

A. Top cover
B. Gas collection system
C. Leachate collection system
D. Intermediate cover

18. Hospital waste comes under _____ waste category.

A. Hazardous
B. Nonhazardous
C. MSW
D. Garbage

19. _____ of hazardous waste is the last priority option in management of hazardous waste.

A. Recycling
B. Treatment
C. Reduce generation
D. Disposal

Answers for Self Assessment

1.	C	2.	A	3.	B	4.	C	5.	D
6.	D	7.	C	8.	C	9.	A	10.	D
11.	D	12.	C	13.	D	14.	C	15.	D
16.	C	17.	C	18.	A	19.	D		

Review Questions

Q1. What is the Kyoto Protocol, 1997? How is it related to the Paris Agreement, 2015? Highlight the difference between the two.

Q2. How is the Montreal Protocol stopping ozone layer depletion? What is the Kigali Amendment, 2016?

Q3. What is the Convention on Biological Diversity? What are Aichi targets?

Q4. How conservation efforts affected tribes? Explain with one example.

Q6. How economic expediency is hurting tribal rights? Explain by taking example of Vedanta-Niyamgiri Hills conflict? Which law was enacted after this conflict?

Q7. How can tribes help in the conservation of endangered species? Explain with one example.

Q8. What are the causes of human-tiger conflicts? How can we resolve human-tiger conflict?

Q9. Explain different categories of solid waste?

Q10. What is integrated solid waste management?

Q11. Explain green product design strategies.

Q12. What is life cycle assessment (LCA)?

Q13. What are eco-labels?

Q14. What are plastics? How could we best recycle plastic waste?

Q15. Explain best strategies used in management of construction and demolition (C&D) debris.

Q16. What are the best strategies for composting?

Q17. What are the advantages and disadvantages of incineration of solid waste? Explain functioning of waste to energy (WTE) power plants.

Q18. Explain construction and functioning of modern landfill.

Q19. What are hazardous wastes? Give examples of hazardous wastes generated in petrochemical, plastic, and electronic industries.

Q20. Explain management strategies of hazardous waste.

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Unit 12: Human Population Growth

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Objectives

After completion of this chapter you will be able to

- understand patterns of world's population growth.
- know the consequences of population growth.
- understand about demographic dividend and dependency ratio.
- understand how development can solve the problems arising from population growth and learn about millennium development goals (MDG).
- understand the ecological footprint of development
- know the transition from MDG to sustainable development goals (SDG).

Introduction

In the recent past, the world's population has grown exponentially. Though the population growth rates are now declining in many countries, still two billion more people would be added to the global population till 2050. (Ref. [1]) We can experience the exponential growth of population in the conversion of a rural area to town, town to city and city to metros in just a couple of decades. With more people we need more clothes, more houses, more food and more gainful employment. If the economic development is well planned and is in tune with population growth, there may not be any crisis in getting standard living conditions for every human on Earth. However, the development based on currently available technologies and policies will be accompanied with rise of pollutant levels in the environment, decline of natural ecosystems, and loss of biodiversity in proportionate manner. We depend on the environment for all goods and services needed to sustain the human economy and the ability of the environment to assimilate waste generated by human societies. The

rising population will strain Nature's ability to supply us vital resources in a sustainable manner due to conflict between use of land for human need and conserving it for natural ecosystems.

The above scenario is an outcome when economic development is well planned to meet projected future requirements, however if there is no proper planning and corruption in government and lack of conscience in businesses prevails then it can lead to widespread poverty mostly due to unequal distribution of wealth. The poverty would result in added difficulties like social unrest (rise in crime rate and terrorism), fast degradation of environment and overall decline of human welfare due to poor education, health and substandard living. In this unit we shall study the patterns observed during the world's population growth, and then we would discuss the consequences of population growth and finally we would learn how we can avoid adverse impacts of population growth by working for sustainable development goals.

12.1 Pattern of Human Population Growth

If we see the trends in human population growth from Stone Age to current time then the human population remains almost constant or increases slightly from 10,000 years ago to almost 1700 AD (Fig. 1). Up to 10,000 years ago, humans had attained food security through the advent of agriculture, but still the human population was controlled by other ecological factors like prevalence of parasitic infections. The high death rate caused by infection induced diseases balanced the high birth rate of the human population, so till 1700 AD it grew only to 600 million. There were also some setbacks to the human population in that period such as black plague of the 14th century. The whole period (10,000 years ago to 1700 AD) is characterized by the spread of human civilization over the planet. The agriculture and natural ecosystems supported the human population and helped them in enhancing their knowledge and mastery of the natural world. However, the natural checks (mainly diseases and other environmental factors) to human population growth were weakened with the simultaneous start of two revolutions: Industrial Revolution and Medical Revolution.

The technological marvels of the Industrial Revolution and advent of use of vast resources of energy contained in fossil fuels revolutionized the manufacturing of essential goods and agricultural production to a level that was not possible by the use of only muscle powers (of animal and human). The increase of useful resources stimulated the increase of the human population. However, continued population growth and economic expansion by fossil fuels powered technologies, resulted in rise in pollution and degradation of natural ecosystems due to extraction of raw materials from all over the world.

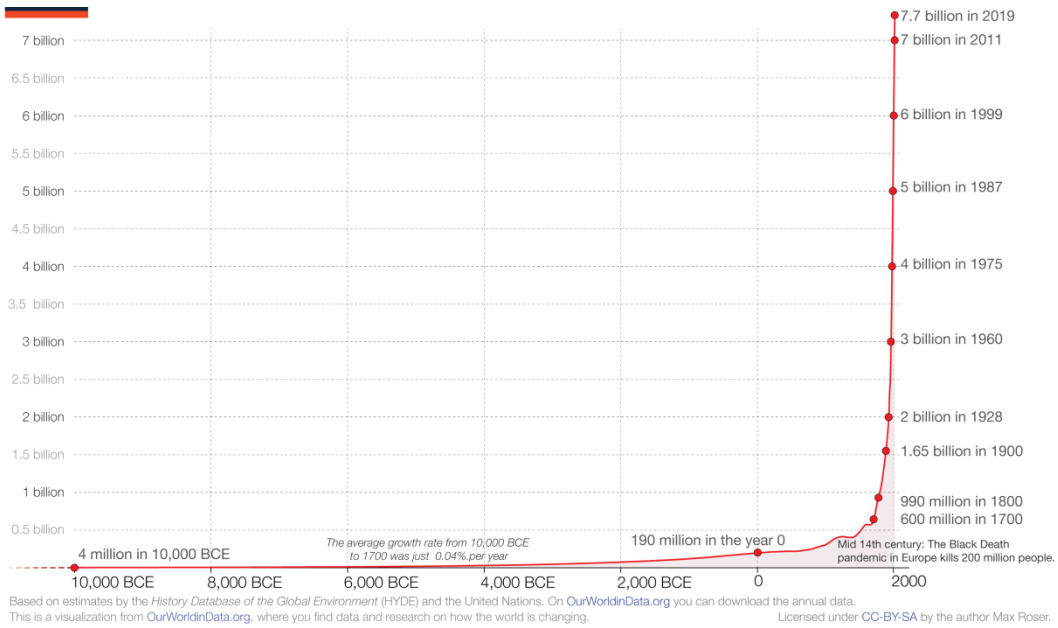

Figure 1. Change of world's population in the last 12,000 years. (Source: Ref. [2])

The other major factor of the exponential rise of population after the 1800s was the Medical Revolution which almost coincided with the Industrial Revolution. The high death rate prior to the 1800s by diseases like smallpox, cholera, diphtheria, measles, scarlet fever etc. was the major cause of slow and fluctuating population growth. Most of the diseases hit children particularly hard and it was not common for a woman giving seven to eight live births to have only two or three children to attain adulthood. In the late 1800s, Louis Pasteur and others discovered the causative agents (now recognized as bacteria, viruses and protozoa) of many infectious diseases. The discovery stimulated the development of medicine and vaccines for these diseases. The development of sewage and water treatment (around 1906) further controlled the spread of diseases, especially waterborne diseases. The understanding of the importance of vitamins in nutrition and discovery of penicillin in the 1930s for treatment of fatal pneumonia and blood poisoning resulted in a drastic decline of death rate. In short, the Medical Revolution is characterized by three aspects: better sanitation, nutrition and medicine. The revolution relieved human suffering by untimely death and morbidity and resulted in low death rate; however, there was no change in corresponding decrease in birth rate. This increased the growth rate of the human population sharply and the human population grew exponentially as shown in Figure 2.

The annual population growth rate was 0.04% from 10,000 BCE to 1700AD, after that it climbed to its maximum value of 2.1% around 1968. The rise of the annual growth rate also led to the exponential rise of the human population. The global population reached the 1 billion mark around 1800 and then it reached the 2 billion mark in 1928 i.e. it just took 125 years to add 1 billion more people. So,

1 billion to 2 billion taken 125 years,

2 billion to 3 billion (1960AD) taken around 30 years,

3 billion to 4 billion (1975AD) taken 15 years,

4 billion to 5 billion (1987AD) took 12 years.

In 1999 the world's population crossed the 6 billion mark and reached 7 billion in 2011. Since currently the population growth rate is declining, the best projection determined by the UN Population Division (UNPD) tells us that our population would stabilize till 2100 and could reach a value of 10.9 billion. The closer projection for 2050 predicts that the world's population could reach 9.7 billion from the present 7.7 billion i.e. almost 2 billion more people will be added in the next 30 years.

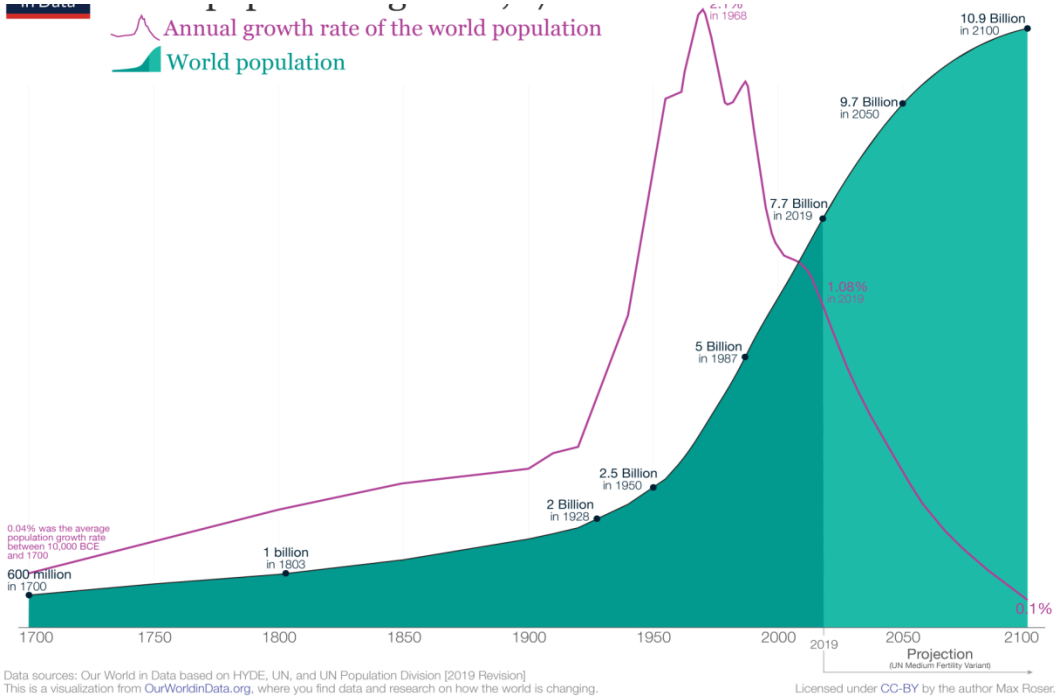

Figure 2. The annual growth rate and growth of the world's population from 1700-2100. (Source: Ref. 1)

12.2 Population Growth in Rich and Poor Countries

Population growth, especially in near history, is not uniform in different parts of the world. The various countries of the world are currently divided in eight sustainable development zones (SDG regions). As per economic status, the nations are further divided by the World Bank as high, middle- and low-income nations. The 2019 criteria of World Bank classifies nations with per capita gross national income (GNI) US$1035 or less as lower income nations, nations with per capita gross national income (GNI) between US$1036 to US$4045 as lower middle income nations, nations with per capita gross national income (GNI) between US$4046 to US$12535 are called upper middle income nations and nations with per capita GNI of US$12536 or more are termed as high income nations. The countries in middle- and low-income categories are also called developing countries and high-income countries are called developed countries.

Most of the developing countries are part of sub-Saharan Africa, Central and Southern Asia, Eastern and South Eastern Asia, Latin America and Caribbean SDG regions. The developed countries are mostly part of Europe and Northern America, Australia/New Zealand SDG zones. As we can see in 2019 World Population Prospects (Fig. 3), the population growth of developing nations is very high, while population growths of developed countries have almost flattened.

High income nations (developed countries) with a combined population of 1.24 in 2010 are growing at a rate around 0.1% annually. These countries add less than one million annually to the world's population. The developing countries' total population was 5.73 billion in 2010. The population of developing countries is increasing at a rate around 1.5% annually. Developing countries contribute approximately 75 million to the world's population annually. Or we can say that 98% of population rise is contributed by developing countries. In fact, the share of least developed countries is highest in population growth. How could we explain this discrepancy?

The discrepancy is related to the origin and spread of the Industrial and Medical Revolution. Just before the Industrial Revolution, the population of many countries were in primitive stability caused by the balance of high birth rate and high death rate. Industrial and Medical Revolutions originated in Europe and then spread to North America, Australia which resulted in almost simultaneous decline of high birth and death rates and now population growth rates in these developed countries are approaching zero. The developing countries started to industrialize late in the mid-20th century. The sudden exposure to marvels of the Medical and Industrial Revolution caused a sharp decline in the death rate but birth rate remained at the same level in developing countries which is the cause of population growth discrepancy mentioned above. However, the population growth rate is declining in many developing nations but it would take long time for these regions to achieve *demographic transition* (a state where low death rate balances with low birth rates) which is achieved by developed countries in mid-20th century.

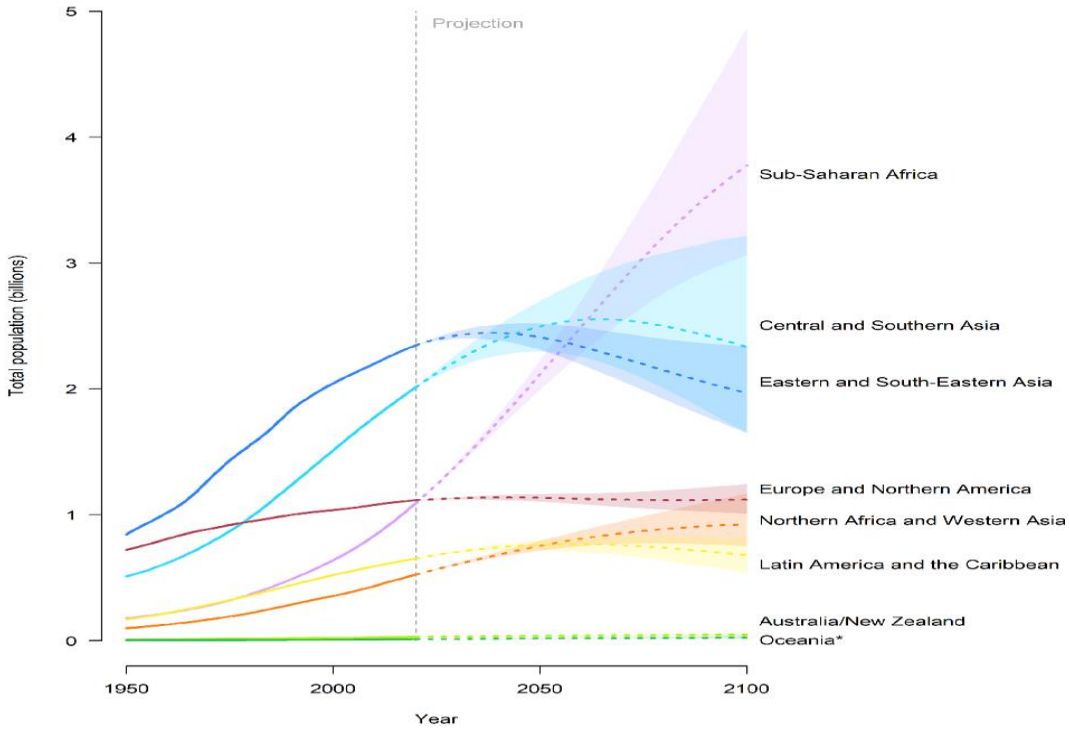

Figure 3. Population growth of various regions (SDG regions) of world and future projection. Shaded areas show variation in future projection. (Source: UN Population Division, World Population Prospects, 2019)

Crude birth rate (CBR) and crude death rate (CDR) are defined as number of births and deaths, respectively, per thousand of a population per year. The term *crude* in CBR and CDR implies that no consideration is given to age, gender, disease, economic status etc. of population in a region. The difference between CBR and CDR can provide us growth rate of population, which is measured in percentage, as follows:

$$Population\ growth\ rate = \frac{CBR-CDR}{10} \quad (1)$$

12.3 Consequences of Population Growth

As per World Population Prospects 2019, two billion more people will be added to our current world's population (7.7 billion in 2019) till 2050. Majority of this rise (≈ 98%) will be contributed by developing countries. With more people comes the need for more food, more houses, more clothes, more gainful employment etc. for which we need economic development. Since the demand in the economy will increase with the rise of population, the supply could also be increased in a profitable manner. Now there is the possibility of two scenarios: (1) Poor planning due to corrupt government and conscience lacking businesses, (2) Economic development is rightly planned as per rising population by an honest government and caring businesses. Let us discuss the impact of population growth in the two scenarios

12.4 Scenario 1: Poor Planning

Prior to the Industrial Revolution, families lived on land, and depended on agriculture and animal husbandry which provided them enough food for survival and for bartering to get other essentials. Forests provided them fuel wood and structural material. This economic system was sustainable and continually provided resources to next generations replacing older ones. Many cultures survived in this way for thousands of years.

The end of World War II introduced modern medicine in the developing world which substantially reduced their death rates resulting in high growth rates as explained in the previous section. Before World War II, the majority of the world's population was living in rural regions and depended on subsistence farming as described in the above paragraph. The rise of population in rural regions and poor planning resulted in resource crunch such as decline in availability of per capita agriculture land, freshwater etc. and consequent reduction in per capita wealth. The lack of sufficient income results in migration to cities, immigration to other countries (both legally and illegally), increases of illicit activities, environmental degradation and creates a poverty trap ultimately declining human welfare. Let's discuss them in detail.

Migration to cities

The lack of sufficient agricultural land due to population growth in rural areas drives people to cities in a hope to earn better income as being an industrial zone the urban centers provide more employment opportunities. However, as supply of workers increases mostly businesses reduce the wages offered to people migrating to urban centers. The lack of investment in skilling the workers for future needs also leads to inconsistent nature of jobs offered to migrating poor people. Further, the cost of basic facilities, food, housing etc. in urban areas are mostly quite higher than rural centers due to high population density induced high demand. These factors lead to urban poverty.

The urban poverty and lack of welfare schemes (due to lower economic growth than population growth in urban centers) makes the migrating people to live in urban slums which mostly emerged as temporary structures on Government land along railway tracks, near river banks, lakes, marshes, on hill slopes etc. These illegal structures often do not have proper drinking water and wastewater management systems, solid waste management and other facilities making urban poor more vulnerable to environmental pollution. Often, the untreated sewage water and solid waste results in pollution of surface and groundwater of the city (Fig. 4). More than one billion people live in these slum areas.

Urban poverty is more serious than rural poverty as rural people can grow their food, have access to free water, fuels and other products. Urban poor only depend on cash to buy all these items. Living conditions of urban poor are generally worse than rural poor. They suffered from both indoor and outdoor pollution.

Figure 4. Dharavi slum in Mumbai, India. (Source: Observer Research Foundation)

Migration between countries

The high GDP and highly paid jobs in developed countries creates a perception in many in low- and middle-income countries that by migrating to these countries, they can raise their living standard. The desperation to go abroad is also the cause of many illegal migrations. Annually around 3.4 million people move to developed countries with 1.2 million only to the US. The high number of entries of immigrants in countries having ethnically and culturally homogeneous societies often leads to prejudice to foreigners. Illegal immigration from developing countries (or less developed country to more developed one) is sensitive political issue in US and many other countries including India.

Illicit activities

Anyone who does not have land to grow enough food should have some income to buy it. When the economy of a region is unable to generate sufficient employment, then it may lead its citizens to engage in illicit activities though sometimes greed can also engage them in illicit activities. These deprived people can be involved in illegal activities like narcotics trade, kidnapping, ransom, robbery including terrorist activities. The poor people of countries rich in biodiversity, also involved in illegal poaching such as in Indonesia, which is suffering from a great deal of poaching of endangered and exotic species e.g. sea turtles, parrots and many other species. The illicit activities also include illegal sand mining in river ecosystems, and mineral mining, timber and other forest produce extractions from protected forests or protected areas.

Poverty trap

The population growth and lack of opportunity to generate sufficient income push the people into poverty. Poverty hinders the children of the poor from getting sufficient and quality education and reduces the economic opportunity available to the next generation of poor persons. This led to the transfer of poverty to the next generation. Low income is also associated with hunger, and poor health and living conditions. Hunger and poor health further decrease the ability of a person to get good education. Poverty also reduces the share of voice of people in Government and their social status. Thus, poverty creates a vicious cycle (Fig. 5) and if poor people are not helped by the State then the cycle could be difficult to break.

The lack of education hinders a person's ability to use family planning schemes properly and sometimes they want to have more children so they can work along with parents to generate more income for the family. In this way poverty is also the cause of environmental degradation (due to living in slums) and high fertility rate of a country.

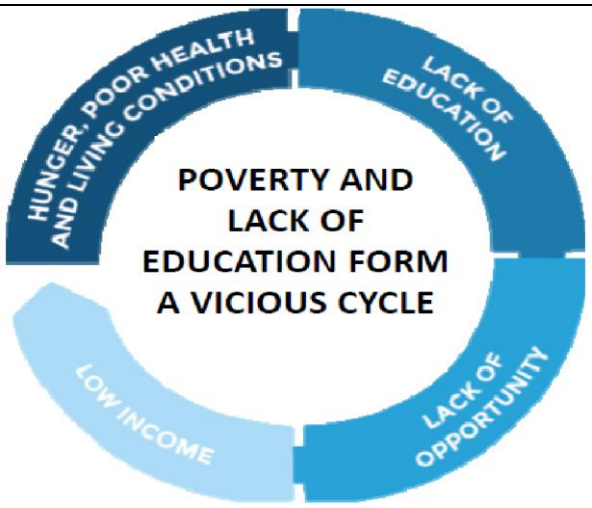

Figure 5. The poverty traps. Cause of high fertility and environmental degradation.

12.5 Scenario 2: Rightly Planned Economic Development

Population growth creates demand in the economy which could be fulfilled by rightly planned industrialization and promotion of agriculture and service sector by government and businesses together. Similarly, the planning could be made to increase the per capita income of citizens in a just and equal manner. This way we can avoid poverty and associated human sufferings discussed above. However, to satisfy the need of growing population land reforms (for equal distribution of wealth), intensifying cultivation and opening up new land (for increasing agricultural and industrial production) are essential. Now let us discuss the impact of population growth in the scenario of rightly planned economic development.

Land ownership reforms

Two patterns which make rural peoples poor are: collectivization and ownership of land by wealthy few. The rising population in rural areas motivates the welfare state for land ownership reforms. Collectivization was a practice of gathering of farmers in group farms and was popular in communist states such as the former Soviet Union and China. The practice was disastrous which led to the failure of Soviet Union. The practice was also abandoned in 1978 in China. The grant of land rights to small scale farmers in China resulted in 6% annual growth of agriculture production for the next 15 years.

The ownership by wealthy few is a practice mostly popularized during colonialism of 19th and 20th centuries like the zamindari system in India during British Era. After independence from colonial rule, many nations tried to change land ownerships, so more landless farmers could increase their income and overall farm output could be increased. These land ownership reforms are mostly resisted by rich and politically influential farmers and also lead to social unrest as events in Zimbabwe have shown us, where a chaotic land reform program destroyed the country's agricultural output and plunged it into economic decline.

Intensifying agriculture

To increase food production to satisfy the needs of a rising population without opening up new land needs intensification of agriculture production from available land. Use of current technologies like improved crop varieties, use of pesticides and fertilizers, and mechanization of agriculture etc. have caused green revolution in many nations. However, the increasing use of the current technological advances in the long run is resulting in soil erosion, water pollution and decline in soil productivity. The adverse impact of current technologies and less climate resilience of current crop varieties are resulting in overall decline of crop production and increasing the input cost of farm production. Surely, we need improvement of current agricultural technologies or need green technologies such as integrated pest management, improved organic farming.

Opening up new land

Another way to increase agricultural production is to open up new land. Land is also needed for expansion of cities for industries, housing complexes, transportation infrastructure, special economic zones etc. But there is no such thing as “new land”. Much of the fertile land is already in use for agriculture; we can only generate new land for above uses by converting natural ecosystems such as

forest, grasslands, wetlands etc. to agricultural land and using already available agricultural land around the periphery of urban centers for expansion of cities. However, the reduction of natural ecosystems means reductions of vital ecosystem services contributed by them and there is also danger of collapse of highly productive ecosystems due to decline of biodiversity. Loss of biodiversity also increases not only reduces the regulative services such as control of drought and floods but could be the cause of the emergence of pandemic due to disturbance of population dynamics of wild species. The reduction of the natural ecosystem is not sustainable for the long term.

Increasing extraction of minerals, freshwater and forest produce

For increasing production of goods needed by human society more natural resources are required. To increase production of metals, alloys and other materials and also to satisfy energy demand we need more ores, minerals, coal, natural gas and crude oil for which new mining sites are discovered and developed. Unfortunately, many times the new mining sites are found in rich forest areas, the mining operation often totally destroys the found on and around the site with resultant decline of ecosystem services. Mining operations also generate a lot of solid waste and pollute freshwater reserves.

Overexploitation of forest produce, especially major forest products, affects habitat of wild species which are an integral part of the forest ecosystem and so functioning of the ecosystem are undermined. Similarly, overexploitation of surface and groundwater lead to decline of water table and associated problems as discussed in unit 3.

Our discussion in the first three units points out that Earth has limited resources, so there is carrying capacity for humans on Earth just like all other species. Through well calculated planning we can reduce the sufferings of humans discussed in scenario one above and we can also raise the per capita income to create not just a society with standard living but a society with affluence. However, Earth has its own planetary boundaries and crossing of these boundaries may lead to collapse of the whole biosphere and consequent elimination of human civilization. Let us discuss what these planetary boundaries are and how we can limit ourselves in these planetary boundaries by minimizing our ecological footprint.

12.6 Planetary Boundary and Ecological Footprint

Planetary boundary

The population of all non-human species are controlled by *environmental limiting factors* such as predators, availability of food, climate extremities etc. We can classify the limiting factors in two major types: density dependent (such as predators, availability of food etc.) which depends on population density of species and density independent limiting factors (such as climate extremities) which has nothing to do with density of population. Limiting factors, which depend on density of population, decide the carrying capacity or how much population of a species is possible in a given habitat. As a limiting factor is relaxed, the population of species increases. For example, rabbits thrive in the field as the amount of grass in the field increases and an alien species could become invasive in a new biogeographic realm due to absence of predators.

The environmental limiting factors are also applicable for controlling the human population in the whole biosphere. However, when human populations were limited by availability of food in one season which could be captured or hunted, the development of agriculture and trade lifted that barrier and led to an increase of human population (at a rate of 0.04% till 1700). When we were limited by energy availability, we discovered the use of fossil fuels and the population started to increase in an exponential manner. When populations were limited by child and infant mortality, medical breakthroughs lowered the mortality and population exploded. Each time a limiting factor is removed population increases till the appearance of a new limiting factor. We may think there is no limit to the human population on Earth as human ingenuity can remove all the barriers. However, this is not true as removal of above barriers increases the carrying capacity of humans on Earth only in a short term. For example, the energy barrier we have removed by exploiting trapped energy in fossil fuels is non-renewable and creating another limiting factor: climate change.

The group of scientists led by Johan Rockstörm and Will Steffen has identified nine planetary boundaries for human population and approximate threshold value for each boundary. Transgressing the threshold of planetary boundaries can create a substantial risk to destabilize the current Holocene state of Earth System (ES), which is the only state of ES that supports contemporary human society. If the Earth System changes to some other state, we are not sure about the future of

human society. The Earth's planetary boundaries provide us safe operating space for human society.[3] Figure 6 shows nine planetary boundaries where the green zone represents safe operating limit, the yellow zone area represents the zone of increasing risk and red areas represent high risk zone.

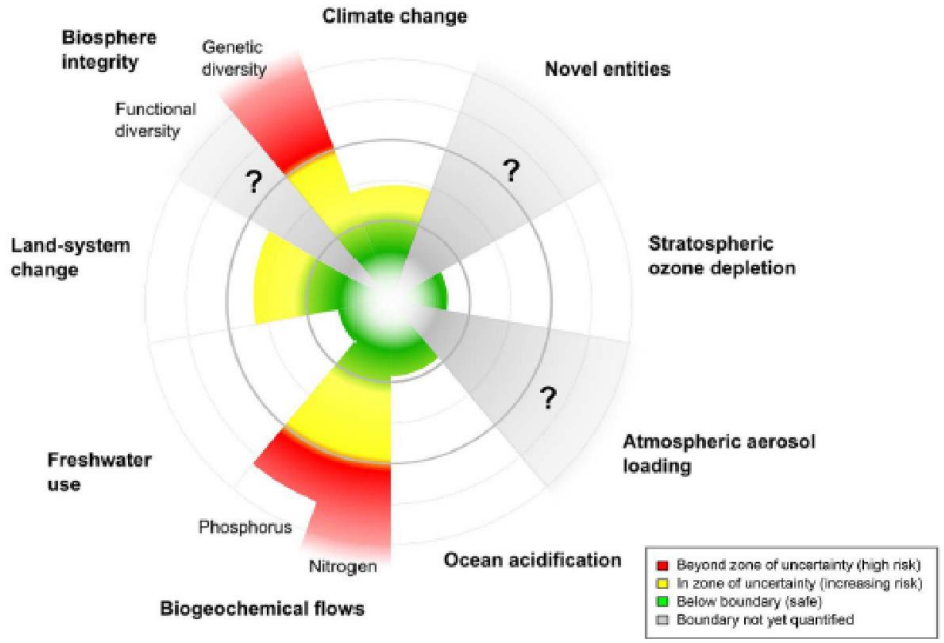

Figure 6. Nine planetary boundaries with their current status of control variable. The status of two planetary boundaries (shown as grey) is not known. (Source: Science, Ref. 2)

The threshold values of a few important planetary boundaries are given in Table 1. As shown in Figure 6 and Table 1 many of the planetary boundaries are already transgressed. The planetary boundary for a novel entity is actually the boundary or limit associated with the amount of pollutants including new chemicals which could be tolerated by our Earth. This boundary and boundary or limit for atmospheric aerosol loading and sub-boundary about loss of functional biodiversity are not known currently.

Table 1. Threshold values of few important planetary boundaries. (Source: Ref. Science, Ref. 2)

Earth system process	Control variables	Planetary boundary	Current value of planetary boundary
Climate change	1. Atmospheric CO_2 (in ppm)	350 ppm	398.5 ppm
	2. Energy balance (W/m^2)	1.0 W/m^2	2.3 W/m^2
Change in biosphere integrity	Extinction rate	<10 E/MSY (extinction per million species-year)	100-1000 E/MSY
Stratospheric ozone depletion	Stratospheric ozone concentration in Dobson Units (DU)	<5% of decrease of preindustrial level (290 DU)	Only decreases over Antarctica at (≈200 DU)
Biogeochemical flow (P-cycle)	P flow from surface runoff into the ocean	11 Tg P/yr	≈ 22 Tg P/yr

For survival, we have to work in a way that above planetary boundaries do not be pushed beyond that threshold. The human need should be fulfilled with minimum impact on the environment or we have to minimize the ecological footprint of human activities. Let us understand what ecological footprint is?

Ecological footprint

We can estimate the overall impact of human society on the environment by a formula first suggested by ecologist Paul Ehrlich and physicist John Holdren. As per their formula (called IPAT formula) the impact I of human pressure on environment could be given by:

$$I = P.A.T \quad (2)$$

Here, P is the population, A is affluence and T is the technology. Affluence A is given by per capita GDP, and T is simply impact I per capita of GDP. Impact I could be CO_2 generated by a country or community or pollutants added to water bodies.

Same population with a moderate consumption level would have less impact on the environment than a population with a lavish lifestyle. Similarly, a large population with the majority of people living below poverty line would degrade the environment in the same way as a comparatively small population with a lavish living standard. For example, the average consumption of US citizens is much higher than a person living in Bangladesh, but the sheer number of people in Bangladesh lead to almost similar environmental degradation as caused by the US at its present per capita consumption level.

Ecological footprint is proportional to impact I explained above. It is the estimate of the area of land and ocean required for supplying resources needed and to assimilate waste generated needed by an individual and society. For example, the ecological footprint of Hong Kong is many times greater than the size of the metropolitan region as it uses resources and affects ecosystems of a much wider area. There are also more specific types of footprints such as carbon, nitrogen, and water.

You can calculate your individual ecological footprint by using an online footprint calculator on the Internet. These calculators will ask you some questions regarding your diet, use of energy, mode transport, recycling and other questions. You may get an answer about how much Earth you need if everyone has a lifestyle similar to you. These calculators are the first step to guide an individual towards a sustainable lifestyle.

IPAT formula and sustainability

From IPAT formula (Eq. 2) it is clear that if we want minimize the impact of human activities on environment or if we want to limit the impact of human activities well below the threshold of planetary boundaries, then we have to minimize the population (lower value of P), if it is not feasible in few coming decades then we can reduce the impact I by promoting conservation (reduction of A) and by developing and promoting green technologies (reduction of T). To achieve sustainability or for operating under the safe limit of planetary boundaries we need the following transition.

1. Demographic transition i.e. population must stabilize.

2. Resource transition i.e. consumption must decrease.

3. Technology transition i.e. movement towards green technologies which should be not only resource efficient, but also should not add pollutants to the environment and promote sustainability.

4. Political/sociological transition i.e. a society where we care for others and work towards eradication of widespread poverty and also care for the rest of the natural world.

Let's discuss in detail about demographic and sociological transitions by which we can resolve our current problems associated with population growth. The technology transition related to the energy sector is already discussed in unit 3 and resource transition will be discussed in unit 11.

12.7 Demographic Transition

Demographic transition is the shift of a nation from high birth and high death rates to low birth and low death rate which mostly happens when a nation industrializes. There are four phases of demographic transition which are mostly observed when a nation industrializes. Phase I is characterized by the primitively stable population of a country in the preindustrial era due to the

balance of high birth and death rates. Phase II is characterized by high growth rate due to large difference between birth and death rates mostly caused by epidemiological transition as a consequence of introduction of medical advances in a nation during its industrialization phase. Phase III is characterized by sharp decline of growth rate as birth rate approaches replacement level and Phase IV occurs when low death rate equalizes with low birth rate and is characterized by almost zero growth rates. Developed nations have reached Phase IV of demographic transition, while developing countries are either in Phase II or III.

The question is what must happen so a nation with a high growth rate can achieve a demographic transition to Phase IV. Before understanding about factors which are responsible for demographic transition lets understand what motivates families in developing countries to have more children.

Causes of population growth

The high total fertility rate (TFR), which is defined as the average number of children that a woman can have during her life span, is the cause of high birth rate and consequent high population growth in developing nations. The major causes responsible for high TFR in developing nations are mentioned.

1. Old age security. An important reason for couples in developing nations to have more children is security for their old age as many developing nations do not provide any pension or safety net for their elderly citizens who are unable to go for work.

2. Infant and childhood mortality. High infant and childhood morality also cause parents to have more children so few of them could survive to adulthood.

3. Helping hands. In subsistence agriculture-based societies in many developing countries, children also work with parents on farms. This makes the parents think that by having more children they can increase their farm productivity. The practice affects the education of children and traps them in vicious poverty cycles leading to environmental degradation.

4. Status of women. The patriarchal social structure in many developing countries discourages women from pursuing higher education, owning businesses and land, and opting for many careers. Respect for women increases as she bears more children.

5. Preference for son. This is another reason for population growth in developing countries with patriarchal social structure as only sons are allowed to own family business. Parents like to stay with sons in their old age as daughters are considered to look after only their husband's home. These customs are responsible for families to prefer sons and women often continue to bear children until she has a son.

6. Availability of contraceptives. Poor women of developing countries often have no access to reproductive health information, and family planning measures available in their country. Lower fertility rate is highly correlated with the percentage of population in the country using contraceptives than with any other factor as found in many studies. Availability of contraceptives is one of the major factors in the fertility transition of Thailand. There are around 215 million women worldwide who do not want a big family and want to avoid unwanted pregnancy but are unable to do so. By reaching these women a significant impact could be made in stabilizing the world's population.

What is needed for demographic transition?

By having the above understanding of causes of population growth, let's discuss what can help a nation towards demographic transition. Most of the developed countries have already achieved demographic transition and there is also good correlation found between per capita gross national income (GNI) of a country and its TFR. So, we may think that "Development is the best contraceptive".

The industrialization and associated urbanization create conducive conditions for couples to have small families like high cost of raising children, old age at marriage, opportunity for women to make money etc. So, the promotion of development in low- and middle-income nations could help the nation in achieving demographic transition. But, mere rise in per capita GDP or GNI of a nation (induced by international aids and assistance) could be deceptive as prevailing inequalities could cause the development to bypass the poor and sociocultural climate favoring high fertility rate may not allow any substantial move towards demographic transition.

The total fertility rate (TFR) of a nation would decline insofar as development provides (1) old age security so parents do not solely depends on children in their old age, (2) medical infrastructure to reduce childhood and infant mortality which make the couple confident that children would survive

to adulthood, (3) universal education at least till high school to children so the chances for them being trapped in poverty cycle could be minimized, (4) improvement of status of women by providing them opportunity for higher education and facilitation in making their career, (5) unrestricted access to reproductive health services and contraceptive. A guided development by high priority public policy incorporating all above factors could help a nation to achieve necessary demographic transition.

Demographic dividend

As countries go through demographic transition an interesting phenomenon happens where the population of the working age group increases in comparison to other age groups. This creates a window of opportunity for rapid economic growth termed demographic dividend. Demographic dividend emerges due to decline of birth rate which leads to increase of working age population relative to younger and older members of population. We can recognize the phase of demographic dividend by plotting the dependency *ratio*, which is the ratio of non-working population (below age 15 and over 65) to working age population, against time. The dividend could also be recognized by plotting population in age group 25-64 with time (Fig. 7). As shown in fig. 7, the demographic window opens for few decades only. The decline of the number of young children due to continuous decrease of birth rate, results in further increase of proportion of older population and consequent rise of dependency ratio. Currently, the highest proportion of the working age population is found in Eastern and South-Eastern Asia. Around 56% of the population of this region was in the working age group in 2019. A nation can take advantage of demographic window to change their economic status, by making necessary investments in health, education and economic opportunities as was done by a number of East Asian and Latin American countries such as South Korea, Brazil and Mexico.

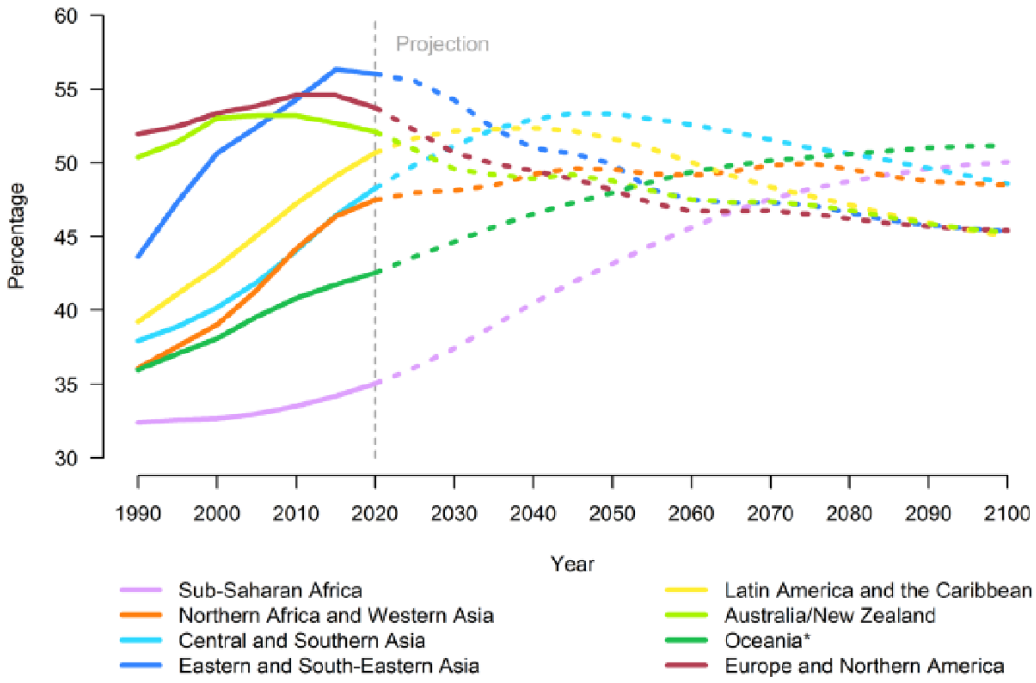

Figure 7. Estimated and projected percentage of population in age group 25-64 in different SDG regions of the world. (Source: UN Population Division, World Population Prospects, 2019)

As was discussed in section 12.4, population growth could lead to a lot of suffering to humanity (poverty, criminal activities, environmental degradation etc.) in case of poor planning to fulfill the needs of rising numbers of citizens. One solution is stabilizing population or demographic transition which is discussed above. In the next section, we would focus on sociological transition or what are the best strategies to minimize human suffering of an already existing high population.

12.8 Sociological Transition

The recent estimate by the World Bank puts the number of poor in the world at 2 billion, if we consider a more realistic and nation specific measure of poverty called societal poverty line (SPL).[4] The societal poverty line is defined as:

SPL = US$ 1.0 + 0.5 x Median (3)

Here, the median is the daily per capita income of a nation.

These poor people often do not have access to clean drinking water, proper nutrition and live in deplorable conditions such as urban poor living in slums. Poverty violates fundamental human rights in similar way as slavery and apartheid had done. The major cause of poverty is the mismatch of development in nations with rising populations. So, we may think the best way to provide standard living conditions to all impoverished citizens of a nation is: promotion of development. The capital could be provided in the form of international aid and loans by the World Bank and other agencies to stimulate development in developing countries. These development aids already helped many developing nations to raise their GDP. However, it is also observed that development often bypasses the poorest people and have even increased their disadvantages. The most probable reason for the discrepancy is the prevalence of high inequality in a nation. A country can have an increase in its GDP, but still many of its citizens would be living in poverty if inequality is high.

12.9 Inequality

The inequality of a nation is measured by the Gini Index. It measures distribution of wealth among members of a nation. Gini index value varies from 0 to 100. A zero value of Gini index means all members of nations have the same income which is equal to per capita GNI (gross national income) and a 100 Gini index means all income of a nation is possessed by one person of a nation. Not so far away, Sweden had one of lowest Gini index (23), while South Africa had one of highest Gini index (65). India's Gini index is also increasing in recent years. Top 1% richest of India possesses 42.5% of national wealth.[5] The United States, an extremely wealthy country, has Gini index 45. In the US the percent of wealth owned by the top 1% have increased from 28% in 1968 to 47% in 2007. The inequality leads to social unrest like the protest "Occupy Wall Street" in the US in 2011. In some low-income countries, top leaders may be extremely wealthy, while the rest of the citizens are poor. Hence, the simple indicator of development such as per capita GNI, life expectancy may not apply to every citizen of a country. The wealth difference between rich and poor of a country also matters.

To make development work for the poor, representatives from the UN, World Bank and Organization for Economic Co-operation and Development (OECD) met in 1997 to formulate a set of goals, which can reduce extreme poverty and its different impacts on human welfare. The goals were further refined and was adopted as a global compact in 2000 at the UN Millennium Summit. The goals called Millennium Development Goals (MDG) were later replaced by Sustainable Development Goals (SDG). Let us learn how these goals can enhance human welfare.

12.10 Sustainable Development Goals and Social Modernization

After the adoption of 8 millennium development goals (MDG) with a total 17 targets associated with different goals at the UN Millennium Summit in 2000 by Member States of UN, a Millennium Project was commissioned by UN to develop a coordinated action plan to achieve MDGs. The 8 MDG were: MDG 1: Eradicate extreme poverty and hunger, MDG 2: Achieve universal primary education, MDG 3: Promote gender equality and empower women, MDG 4: Reduce child mortality, MDG 5: Improve maternal health, MDG 6: Combat HIV/AIDS, malaria, and other diseases, MDG 7: Ensure environmental sustainability, MDG 8: Forge a global partnership for development.

The Millennium Projects involving 250 development experts found out that the majority of MDGs could be achieved till 2015 which was also set as the target date to achieve MDGs. All the 8 MDGs have progress indicators such as MDG 4 (Reduce child mortality) indicators: infant mortality rate, under-five mortality rate, proportion of one-year-old children immunized. An assessment of progress towards MDGs identified in 2011 that the majority of goals were on the verge of touching their set targets such as for MDG 2, the enrolment in primary education were reached to 90% and higher in all but two regions. However, the goal with the greatest number of targets worsening was

MDG 7: Ensure environmental sustainability. This led UN Member States to modify MDGs, so development could be achieved without decreasing ecosystem services and sustainable development goals was framed at the 2012 Rio +20 meeting.

Sustainable development goals (SDG) were adopted by UN Member States in 2015 (the end of target date of MDGs) with universal call to action to end poverty, protect the planet, and ensure peace and prosperity to all people by 2030. There are a total 17 SDGs as explained in Figure 8.

Figure 8. Sustainable development goals for protecting the planet and achieving prosperity. (Source: United Nations, Ref. [6])

The solutions which can help poor people to improve their income and wellbeing also motivate them to opt for small families. Similarly, the solutions which can help in stabilizing the population (section 12.6) also bring prosperity in regions. So, poverty eradication and demographic transition are interlinked. SDGs can help us to achieve five important components of social modernization which are mentioned below.

Improving education.

Investing in the education of children and adults who lack education can fetch a rich dividend. For example, in 1960 both Pakistan and South Korea had similar income and population growth rates (2.6%), but enrolment rate in South Korea was 94% while in Pakistan it was 30%. Within 25 years, South Korea's GDP growth was three times that of Pakistan and its population growth rate declined to 0.5% while Pakistan's population growth rate is still at 2.2%. The SDG 4 is about ensuring quality and lifelong learning for all. Evidence shows that even achieving 50% of quality secondary education can lift a large segment of a poor country's population out of poverty and affect the total fertility rate of the country strongly.

Improving health.

Life expectancy is a universal indicator of human health. There is a big difference in life expectancy between developing and developed countries. For example, life expectancy of Monaco and Japan is more than 80 years, while for Chad, Afghanistan, South Africa and several other developing countries is as low as 49 years.

To enhance the life expectancy focus should be on diseases which are the major cause of deaths in high mortality countries. In poor countries, it could be malnutrition and common infections. The primary health services in a country need to be centered on the needs of the community, and must be accessible to every citizen.

A very important aspect of improving health is reproductive health. It is focused on women and infants and in some cases on reproductive education and health for men. Reproductive health involved several key components: prenatal care, postnatal care, prevention and treatment of sexually transmitted diseases (STD), legal abortion services, and prevention and treatment of infertility. The promotion of reproductive health also involves protection of women from violence and coercion. It

should be clear to us, "When women are better off, whole populations are improved." Improving health is covered in SDG 1, 3, 5 and 6 (Fig. 8).

Family planning.

The goal of family planning is about enabling people to plan their own family i.e. they can have children only if and when they want. This is possible by vigorous promotion of information (including their provision) of contraceptives and related materials, and treatments to stop unwanted pregnancy. The dedicated family planning departments and agencies supported by Government and international group are essential for achieving the goal of family planning.

The effective implementation of family planning is one of the most reliable ways for reducing the total fertility rate of a nation. For example, a vigorous family planning program was implemented in Thailand, as part of their national population policy in 1971, which resulted in decline of population growth from 3.1% per year to 0.5% per year. Family planning is also one of the critical components of reproductive health care.

Women who do not want childbearing but lack the access or information about contraception constitute the *unmet need* in family planning. There is 10% to 50% unmet need for family planning in different developing countries. The availability of family planning service also avoids abortions (to terminate unwanted pregnancy) which are not allowed in many countries and can also be risky to mothers. Family planning is part of SDG 3 (good health and wellbeing), but SDG 3 could be strengthened by ensuring SDG 4 (quality education), SDG 5 (gender equality), SDG 8 (decent work and economic growth) and SDG 16 (peace, justice and strong institutions) for women.

Employment and income.

The basis of any economic system is exchange of goods and services. In the primitive economy called barter economy people directly exchange goods and services. Barter economies still exist in many developing countries. The introduction of cash in the economy increases the prosperity of everyone as people can find a wider market for goods or services which they can offer and have wider choice for what they can get in return.

In a poor community where every member has the potential to offer some goods and services, but lack of cash hinders the smooth start of the economic system. People in a growing economy mostly secure bank loans to start their business ventures. However, the poor are generally considered high credit risks. Sometimes, they only want a small sum of money for their business requirement which a commercial bank may not deal with. Many of the poor are women whom commercial banks do not consider credit worthy simply due to gender bias. The above three reasons are responsible for poor not getting start-up capital as is possible by wealthy and privileged members of society. Fortunately, a good solution was found to the above problems in the form of the Grameen Bank system (See the case study below). SDG 4 (Quality education), SDG 8 (Decent work and economic growth), SDG 9 (Industry innovation and infrastructure) and SDG 10 (Reduced inequality) are involved in achieving the 'employment and income' component of social modernization.

Grameen Bank

To resolve the problems (mentioned above) faced by poor, economics professor of Bangladesh Muhammad Yunus created a new kind of bank, now called Grameen Bank. Grameen Bank is involved in microlending to the poor. It distributes small (2011 average was US$ 370) and short-term loans to poor entrepreneurs such peasants, beavers, bakers, auto mechanics etc. These loans may help peasants to seed in showing seasons, beavers to buy yarn, bakers to buy pan, and an auto- mechanic to buy essential tools.

The bank secures its loans by lending only to members of the *credit association*. The credit associations are a group of several people who are responsible for each other's loans. The members of the credit association co-operate and support each other. The credit association is also helped by advisory groups in a given field such as horticulture advisory groups which provide the members with advice related to market demand, best suited technology etc. This arrangement of the bank results in around 97% payback of loans given mostly to people considered high credit risk by normal banks. In a rural area of Bangladesh peasants doubled their incomes in three years through assistance from the Grameen Bank system.

The Grameen Bank concept has been adapted by more than 40 countries around the world with various modifications. The World Bank through Consultative Group to Assist the Poorest (CGAP) is also providing great support to 54 different funding agencies involved in microlending. As per Microcredit Summit Campaign, in 2010 some 137.5 million microloans were in service helping more

than 687 family members. Professor Yunus was awarded the 2006 Nobel Peace Prize in recognition of the success of the Grameen Bank concept.[7]

Resource management.

Majority of the world's poor depend on ecosystem capitals found near their locality. Particularly, they use water and soil for growing food (maintained by local ecosystems), and forests for firewood. Many lack sufficient access to land to get enough income. These landless people (around 90% of the poorest persons of the world) generally depend on common pool resources provided by local ecosystems. They mostly depend on forests for extracting fuelwood, construction wood, wild fruits and herbs and "bush meat" for subsistence and cash. The natural ecosystems (forests, grasslands, coral reefs, rivers etc.) are a safety net and employment source for the world's poor. However, if these resources are not managed properly especially when population is increasing, the common pool resources are liable to decline due to overexploitation. Though the poor section of the population would be worst affected, reduction of ecosystem services may also affect global GDP.

One of the best ways of managing natural ecosystems is empowering the poor, who's living directly depends on natural ecosystems, for managing the natural ecosystems. For example, in Nepal forestry users (mostly tribal and rural persons) are given rights to own trees but not land. There are now around 6000 user groups managing 450,000 hectares of forest land in Nepal. The user groups develop plans to manage forests, decide the price of timber and manage the profits earned through sustainable forestry. The management of ecosystem services for current and future generation in a way that they does not decline but help in increasing wellbeing of humans are part of SDG 9 (Industry, innovation and infrastructure) SDG 11 (Sustainable cities and communities), SDG 12 (Responsible consumption and production), SDG 13 (Climate action), SDG 14 (Life below water) and SDG 15 (Life on land).

All of the sustainable development goals (SDGs) discussed above are actually interlinked. These SDGs could be achieved in a better way if they are approached in an integrated manner. For example, just achieving SDG 14 (Life below water) and SDG 15 (Life on land) can directly help us in achieving ten SDGs which in turn can help us in achieving the remaining five SDGs (Fig. 9).

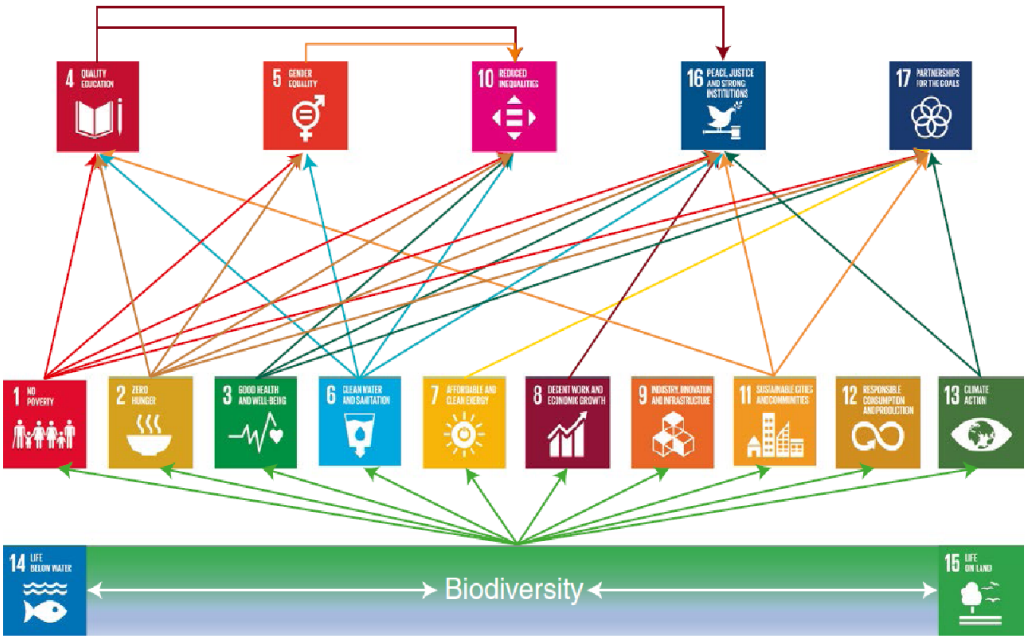

Figure 9. Integration of SDGs. How achieving SDGs in the bottom row (SDG 14 and SDG 15) associated with biodiversity can directly help us in achieving ten SDGs shown in the middle row which in turn can help us in achieving the remaining five SDGs. (Source: Ref. [8])

To meet the Sustainable Development Goals, a nation has to keep pace with its population dynamics. They also need wise leaders, effective public policies, technological and financial help from wealthy nations. Meeting these needs is a matter of ethics: environmental ethics.

Summary

Human population has grown exponentially in the last two centuries mostly because of the combined impact of the Industrial Revolution and the Medical Revolution. The late arrival of marvels of the two revolutions in developing (middle and low income) countries has led to high population growth rate in these countries. Currently, around 98% of the world's population growth is contributed by developing countries while populations of developed countries have almost stabilized. The rise of population brings with it more demand for food, houses, clothes, gainful employment etc. These demands require more economic development in a nation. Now there are two scenarios: (1) development is poorly planned due to corruption in government and lack of conscience in businesses, (2) Development is planned as per dynamics of rising population. The scenario one can lead to widespread poverty and consequent social unrest due to illicit activities leading to immense human sufferings. Scenario two may not reduce human welfare due to the rise of production of goods and services including income and employment as per rising human needs. However, scenario two may not be sustainable since planet Earth has its limit in providing for the needs of a rising population. There are nine planetary boundaries which if continuously violated can lead to collapse of the whole biosphere and consequent elimination of human civilization. The value of control variables for these nine boundaries (such as rise in CO_2 level and radiative forcing for the planetary boundary; climate change) has already been estimated. The impact of rising human population on the environment (which could be measured in terms of control variables of planetary boundary) may be approximated by formula "I = P.A.T". In the formula, *I* denote the impact on environment, *P* the population, *A* is affluence and *T* is impact of technology used. Clearly, the impact on the environment of the human population could be minimized by lowering *P* (demographic transition), lowering *A* (resource and sociological transition), and lowering *T* (technological transition i.e. development of green technologies with minimum impact on environment). Demographic transition is about stabilizing population which could be achieved by development if it could provide old age security, medical infrastructure to reduce childhood mortality, universal education, improvement of status of women and access to family planning services. To lower the parameter *A* of the formula we need both decrease in consumption termed resource transition and decrease in inequality or poverty reduction termed sociological transition. The solutions which are needed for demographic transition also induce sociological transition and similarly solutions which are needed for sociological transition also help a nation to achieve demographic transitions. Hence, Millennium Development Goals (MDGs) were formulated by the UN to remove the curse of poverty from humanity and got adopted by all its Member States with target year 2015. A lot of progress was made in achieving most of the goals except MDG 7: Ensure environmental sustainability. To combat this deficiency new Sustainable Development Goals (SDGs) were adopted by the Member States with their target year 2030. There are 17 SDGs which work to achieve five major components of social modernization: improving education, improving health, family planning, employment and income, and resource management. A quality education, good health coupled with better opportunities for employment or business could improve the living standard of citizens of a nation. This is possible only if the population is stabilized, ecosystems including its biodiversity are maintained and investment is made in technological innovation.

Key words

Exponential population growth, The Industrial Revolution, The Medical Revolution, Crude birth rate, Crude death rate, Population growth rate, Total fertility rate, Migration to cities, Urban poverty, Migration to countries, Poverty trap, Land reforms, Intensifying agriculture, Opening up new land, Planetary boundaries, IPAT formula, Demographic transition, Phases of demographic transition, Demographic dividend, Sociological transition, Gini index, Millennium Development Goals, Sustainable Development Goals (SDGs), Social modernization, Grameen Bank, Societal Poverty Line (SPL)

Self Assessment

1. The cause of exponential population growth after 1700 is _____

A. Industrial revolution
B. Neolithic revolution
C. Medical revolution
D. Both industrial and medical revolution

2. _____ is one of the causes of population growth in India.

A. Preference for daughter
B. Preference for son
C. One child policy
D. Dowry demand for marriage

3. Of the nine parameters of planetary boundary, which of the following parameter is getting constrained due to discharge of more nitrogen nutrient in ocean?

A. Climate change
B. Global freshwater use
C. Ocean acidification
D. Flow of nutrient cycle

4. Rising population and _____ leads to increase of poverty.

A. Lack of modern medical facilities
B. Lack of economic opportunity
C. Lack of entertainment industry
D. Good economic growth

5. Illicit and criminal activities are the consequence of _____

A. Land reforms
B. Environmental degradation
C. Climate change
D. Poverty

6. Impact of rising population on environment is dependent on current population, affluence and _____

A. Growth rate
B. Birth rate
C. Technology
D. GDP

7. Development is best strategy to stop population growth since _____

A. People could be paid for to keep family size small
B. It provides old age security
C. It lowers infant mortality
D. Both it provides old age security and lowers infant mortality

8. Development could be failed to mitigate consequences of population growth if _____

A. There is no green technology
B. There is high inequality
C. Mortality rate is high
D. There is continuous rise of CO_2

9. Dependency ratio of a population is defined as _____

A. Ratio of working population to nonworking population
B. Ratio of nonworking population to working population
C. Ration of population aged above 65 to total population
D. Ration of population below poverty line to total population

10. Dependency ratio of India is _____

A. Increasing

B. Decreasing
C. Constant
D. Zero

11. To make the most of the demographic window, investment should be made in _____ for the young generation.

A. Unemployment allowances
B. Education
C. Increase of economic opportunities
D. Both education and in increase of economic opportunities

12. The GDP of a nation is increasing and still many people remain in poverty, then it shows _____ is high.

A. Equality
B. Inequality
C. Population
D. Pollution

13. Poverty leads to environmental degradation due to _____ of natural resources.

A. Sustainable use
B. Inefficient use
C. Unsustainable use
D. Inefficient and unsustainable use

14. Poverty leads to _____ due to lack of access to education.

A. Low fertility rate
B. High fertility rate
C. High GDP
D. High generation of intellectual property

15. Millennium Development Goals of UN was made _____

A. To increase sport infrastructure in nations
B. To establish cultural exchange among nations
C. To establish strategic cooperation among nations
D. To end world's poverty

16. Millennium Development Goals (MDG) was replaced by _____ in 2015.

A. MDG Part 2
B. Decadal Development Goals
C. Sustainable Development Goals
D. Economic Development Goals

17. SDG 4 (Quality education), SDG 8 (Decent work and economic growth), SDG 9 (Industry innovation and infrastructure) and SDG 10 (Reduced inequality) are more focused on achieving _____ component of social modernization.

A. Family planning
B. Improving health
C. Employment and income
D. Resource management

Answer for Self Assessment

1.	D	2.	B	3.	D	4.	B	5.	D
6.	C	7.	D	8.	B	9.	B	10.	B
11.	D	12.	B	13.	D	14.	B	15.	D
16.	C	17.	C						

Review Questions

1. Explain trends observed in the growth of the human population of the world.
2. Why is the population growth rate high in developing nations in comparison to developed nations?
3. Discuss the impact of population growth in case scenario one: Poor management.
4. Discuss the impact of population growth in case of scenario two: Well planned development.
5. What are planetary boundaries?
6. How could we approximate the impact of population growth on the environment in scenario two Well planned development?
7. What do we mean by ecological footprint?
8. Using the IPAT formula, explain how we can achieve sustainability?
9. Explain various phases of demographic transitions.
10. How development could help in achieving demographic transition?
11. What is sociological transition?
12. Explain origin of Sustainable Development Goals (SDGs).
13. How can SDGs move us towards social modernization?

Further Reading

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Unit 13: Disaster Management

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Objectives

After completion of this chapter you will be able to

- know about disaster management
- learn about flood risk estimation of a given area.
- learn mitigation strategies to reduce the impact of floods.
- learn what causes an earthquake.
- understand management strategies of earthquakes.
- learn the causes and management of cyclone disaster.
- learn causes and mitigation of impacts of landslides.
- understand the causes which led to Chipko and Silent Valley movements.
- understand the factors which contributed to successes of these movements.
- learn the impacts of these movements.
- know about the Bishnoi community.
- know the causes and impacts of the great sacrifice made by Bishnois in 1730 AD.

Introduction

We have learned in unit-9 how global warming is increasing adverse weather events such as flood, drought, and tropical storms. Even if there is a rise in adverse weather events, still we can scientifically manage them to minimize human sufferings. In this unit we shall discuss the best management practices of natural disasters. In addition to weather related disasters like floods and cyclones, the management of earthquakes and landslides would also be discussed in this unit. The second part of the unit is about the study of popular environmental movements. We shall learn about Chipko and Silent Valley movements to know how people have deep recognition of the

importance of the environment and how their love for the environment could move masses against practices destroying the environment. We would learn about how the Bishnoi sect is based on promotion of environmental conservation and how the deep rooted love of Bishnois for the principles defining their sect has led to great sacrifice made by Bishnois in 1730.

13.1 Disaster management

There is no country in the world which is immune to disaster, although the vulnerability may vary from one region to another. The frequency of these disasters has increased in the present time due to the climate change in the world. Disaster Management is a strategic planning and procedure administered and employed to protect lives and critical infrastructures from severe damages which occur during natural or human made calamities. It's plans are aimed to the face the damages brought by floods, hurricanes, landslides, earthquakes and even mass failures of utilities or the rapid spread of disease. The disaster plan aims to relinquish people from an impacted region, arranging temporary housing, food, and medical care. The objectives of disaster management are to reduce or avoid losses from disasters, to assure assistance to victims and hence achieve rapid and effective recovery.

Resilience and prevention efforts, initiatives, and programs were made a part of Emergency Management by the United States Department of Homeland Security (DHS) and the Federal Emergency Management Agency (FEMA). Resilience is defined as the goal of mitigation, preparedness, response, and recovery; which aids to recover from the misfortune while Prevention helps to avoid danger or risky events. Disaster Management consists of systematic processes which lead to action before, during and after a disaster to save lives and prevent injury to infrastructure. It is organized into four phases: **Mitigation:** actions which are taken to reduce its potential impact of a hazard or eliminate it, **Preparedness:** planning how to respond to a disaster, including training and exercises, this also requires coordination between different departments such as health and police departments and NGOs **Response:** Taking quick and immediate actions taken in response to emergencies to save life and property, providing medical relief, etc., **Recovery:** actions which are taken after the disaster and help to restore services and reconstruct communities and return the communities to normal conditions.

13.2 Management of Flood

Floods are the overflow of water that submerges the land that is usually caused by heavy rainfall, rapid snowmelt or a storm surge from a tropical cyclone or tsunami in coastal areas. These are the most frequent type of natural disaster that can cause widespread devastation, causing loss of life and damages to personal property and critical public health infrastructure (Fig 1).

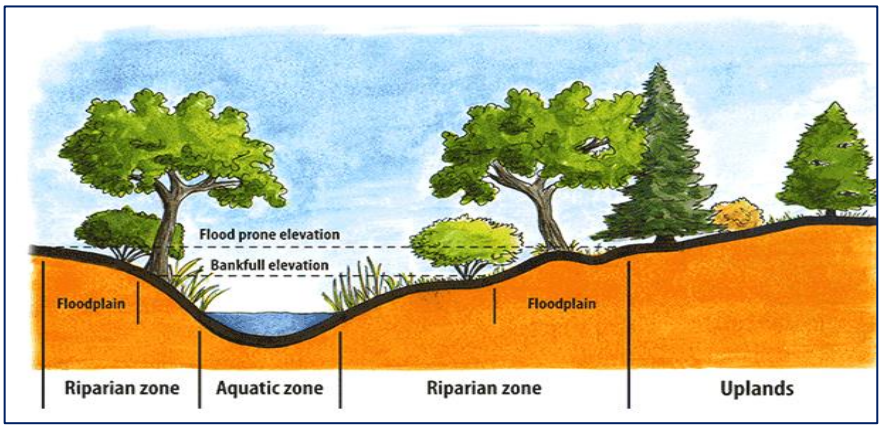

Figure 01: River and its associated plain and riparian zone

Flood risk assessment includes study of areas situated in flood plains and coastal zones and analysis of past flood events. It is an important measure to manage and mitigate the floods. In order to assess the risk of flood in a given region, identification of flood prone elevations in the river basins should be done along with the analysis of past flood events of the particular region. Such analysis can help us to predict the probability of rainfall in the region and accordingly we can demarcate the flood prone areas well in advance before the disaster. These steps become important

as most of the communities reside near the flood prone areas in order to assess the freshwater resources and fishes. But floods which are actually not a disaster but a natural blessing needed to manage river ecosystems become harmful for such people who inhabit the flood prone areas. Most of the river basins have thick forests such as tropical forests which actually act as buffer and help to protect the nearby human settlements from devastating effects of flood. These forests in the watershed regions minimize the velocity of water which moves from banks of river toward human settlement areas. More forest increase the detritus of the soil which further increase the water absorbing capacity of the soil and also decrease the velocity of moving water. Deforestation of these areas leads to entry of water in city. Most of the ancient civilizations started near rivers beds and in recent time more than 50 percent cities are situated near water bodies.

Major flood prone areas in India are Gangetic plains of UP, Bihar, West Bengal and the flood plains of Brahmaputra in Assam. The Ganga Brahmaputra basin receives maximum run off within three monsoon months that is from mid of June to September. Floods in Kosi river in Bihar and Brahmaputra river are quite common in these months. Floods in coastal regions include Cyclones, Hurricanes and Typhoons. Tsunamis are one of the rare causes in these areas which occur when an earthquake epicenter occurs in ocean crust. Due to this the ocean bed moves in the vertical directions and this leads to waves in the ocean of the height of around 10m which becomes a devastating coastal flood. Such a Tsunami was experienced in Indonesia in 2004. A major cause of the increase in the frequency of flood is the climate change.

Case Study: Flood in Bangladesh

Bangladesh is said to be a country of rivers. About 66% (144,000 km^2) of land in the country is either floodplain or delta. Bangladesh receives about 75% runoff from Himalayan mountains which drain through the country. The mean annual rainfall is very high as 1500 – 3000 mm/yr. The rivers of Brahmaputra, Ganges and Meghna peak in the months of August or October and one third of the flooded area comes under at least 1m of water. These data clearly indicate the severity of the disaster in the country. Along with these river floods, the country also suffers from coastal floods which come due to recurring lethal coastal storm surges in cyclones. Astronomical tides which come with cyclones during high tides add to the severity. These astronomical tides cause the oceanic water to extend up to 300 km offshore. The funnel shape of the bay takes a right-angle change in the coastline and further causes maximum storm surge levels over Bay of Bengal. The number of fatalities which occurred in Bangladesh due to flood was as high as 3,00,000 in 1970 which clearly indicates that Bangladesh is at high risk of river as well as coastal floods. For mitigation of floods in Bangladesh a 10-day flood forecast and warning system has been developed which allows implementation of emergency response plans. This plan helped in saving US$270 per household in 2009.

Mitigation of floods: Problem for flood mitigation finds its solution in green engineering which involves sustainable practices. Some of the unsustainable practices in river corridors and coastal areas are intensively engineered structures, dense population and lack of biodiversity. Green Engineering involves new structural and other solutions and to provide a sustainable economy for many human generations. Another solution may be building of flood walls of high strength and height above the average elevation of flood water and floodplains should not be used for human settlements. Response system also plays a major role in flood mitigation. Advances should be made in meteorological forecasting with proper implementation of warning systems. Proper warning system and announcement through television and radio should be made at least one day before. After the dissemination of a warning message, people should be evacuated with proper plans especially for the elderly, poor or people in the hospitals. In order to properly evacuate the people vehicles should be arranged keeping in mind the population in the area. There should also be proper inter-sectional and inter-departmental coordination so that people know where to go and whom to contact. Acquisition and relocation becomes another important step in flood mitigation. People from the flood prone area can be relocated to some other safe area which is the most sustainable solution. High rise topography can be utilized for such relocations. It is not that the whole community needs to be relocated but a section of people residing near to coastal areas can be moved. The vacated land can be utilized for the improvement of the river ecosystem and the services provided by this improved river ecosystem will give the benefit-cost ratio that ranges from 1.67-2.91. Thus, relocation is not a burden but can be a profitable investment for the people.

Floods by themselves are actually not a disaster but a blessing because inland floods bring nutrients to the soil which makes it more fertile. This reduces the input cost of agriculture as there is no need

for manure or fertilizers after the floods make the soil rich in nutrients and hence more fertile. Floods are also essential to maintain complex and biodiversity rich ecosystems.

13.3 Management of Earthquake

Earthquake is defined as any seismic event which is caused naturally or as a consequence of human activities, and leads to the generation of devastating seismic waves.

Major natural causes of earthquakes include Tectonic movements and volcanic eruptions which lead to major huge damage and major destructions (Fig 2). Man-made causes include mining activities which include collapse of roof of underground mine, chemical or nuclear explosion leading to explosion earthquakes which occur especially at nuclear testing sites. Dams containing huge amounts of water may lead to a pressure on our Earth crust and cause reservoir induced earthquakes. Excessive extraction of groundwater especially in regions situated near the tectonic plates may also cause earthquakes.

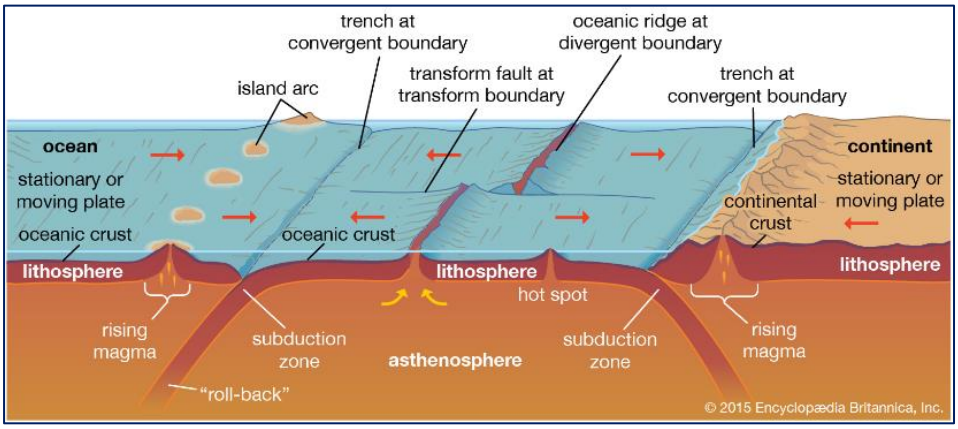

Figure 02: Tectonic movements.

An earthquake occurs when two blocks of the earth suddenly slip past one another. The point below the earth's surface where the earthquake started is termed as the focus or hypocenter, and the point directly above it on the surface of the earth is called the epicenter. Our earth comprises of four major layers: the inner core, outer core, mantle and crust. These layers are not all in one piece but made up of many pieces. We call these pieces tectonic plates (fig 3), and the edges of these plates, the plate boundaries. The tectonic plates keep slowly moving around, sliding past one another and bumping into each other.

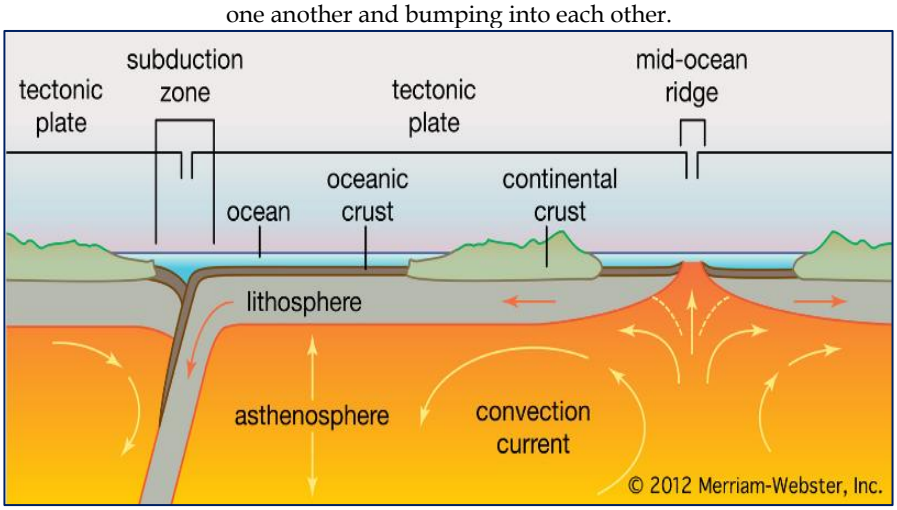

Figure 03: Subduction and mid-ocean ridge.

While the tectonic plates are moving, the edges of the plates get stuck due to their rough texture and after the plate has moved far enough, the edges unsticks on one of the faults and there is an earthquake. The force of the moving block overcomes the **friction** of the jagged edges of the fault

and it unsticks, then all the stored up energy is released. This released energy is radiated outward from the fault in all directions in the form of **seismic waves** just like ripples on a pond. These shake the earth when they move through it, and as the waves reach the earth's surface, they shake the ground and anything on it. Earthquake waves broadly comprise body waves and surface waves (Fig. 4). Body waves are of two types: P or Primary waves and S or Secondary waves. P waves are called so because they are the first type of wave to arrive at seismic recording stations. This causes the ground to compress and expand in the direction of travel and can travel through solids, liquids, and even gases. S waves cause shaking of the ground in a crosswise motion that is perpendicular to the direction of travel. When both P and S waves have moved through the body of Earth, surface waves develop which travel along Earth's surface. Surface waves travel only through solid media but are much larger and more destructive. Magnitude of energy released during an earthquake is measured in the Richter scale.

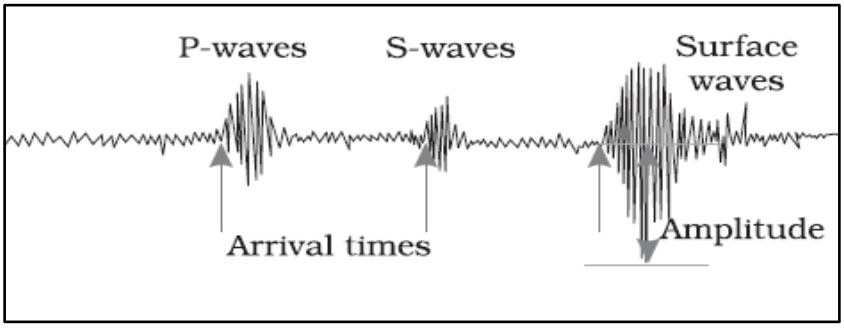

Figure 04: Different types of waves in Earthquake.

Earthquakes cause a major impact of landforms in the forms of Ground Shaking, Soil liquefaction, Avalanches and Ground displacement. Impact of earthquake on humans includes floods from dam and levee failures, fires, structural collapse, falling objects and Tsunami.

Case study Bhuj Earthquake

Bhuj Earthquake was a massive disaster which occurred on Jan 26, 2001 in Gujarat, India at 08:46 AM (Fig. 5).

Figure 05: Destruction caused by Bhuj Earthquake.

Measured 7.7 on the Richter scale, it caused the killing of 13805 people and injured more than 1,50,000 others. In order to support the recovery, an aid of US$ 180m was given from Gujarati NRI. There was also a US$ 2b Reconstruction grant from the government.

Mitigation of earthquake can be done by constructing buildings as per modern structural engineering technology (Fig. 6)

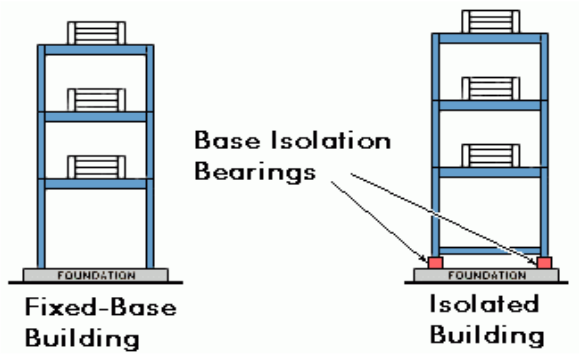

Figure 6: Structural engineering technology for mitigation of earthquakes.

13.4 Management of cyclone

Cyclones are a rotating, organized system of clouds and thunderstorms that originates over tropical or subtropical waters and has closed, low-level circulation. The main causes are large sea surface with temperature higher than 27° C and pre - existing low pressure area. These cyclones draw their energy from the sea surface and maintain their strength as long as they remain over warm water. A tropical cyclone generates winds that exceed 119 km to 320 km per hour. Along with these strong winds also occur torrential rains and a devastating phenomenon known as the storm surge, an elevation of the sea surface that can reach 6 metres above normal levels (Fig. 7).

Figure 7: Cyclone causing storm surge.

This combination of high winds and water creates a serious hazard for coastal areas in tropical and subtropical areas of the world. Areas affected by these tropical cyclones get typically large amounts of water into the areas. These rainfall rates may overwhelm the capacity of storm drains and result in local flooding. Severity of these floods is more in low-lying regions such as in Bangladesh and the Gulf Coast of the United States.

These are known by different names in different parts of the world. These storms are called hurricanes in the North Atlantic Ocean and the eastern North Pacific, typhoons in western North Pacific around Japan, and China. They are variously referred to as severe tropical cyclones, tropical cyclones, or simply cyclones in the western South Pacific and Indian Ocean.

Case Study: Hurricane Katrina

The southeastern United States was struck by a tropical cyclone Hurricane Katrina on 29 August 2005. The hurricane and its aftermath caused about 1836 fatalities 1836and a loss of about US$ 100 billion. It is ranked as the costliest natural disaster in U.S. history. Hurricane Katrina had a Category 3 rating on the Saffir-Simpson Hurricane Scale at the time when it made landfall. The hurricane was associated with sustained winds of 100–140 miles per hour–and it stretched

some 400 miles across. Although the storm did great damage both to lives and the economy, its aftermath was catastrophic. Levee breaches caused massive flooding, and people even charged that the federal government was slow to meet the needs of the people affected by the storm. Hundreds of thousands of people were displaced from their homes in Louisiana, Mississippi and Alabama.

The Indian Scenario of Cyclones is that India witnesses 5-6 Tropical Storms mainly in Bay of Bengal and Arabian Sea. The frequency is more in the Bay of Bengal. The mitigation of cyclones involves installation of early warning systems and development of communication infrastructure as shown in figure 8. Cyclones can be forecasted with the help of satellites which will be helpful in knowing the timing of landfall.

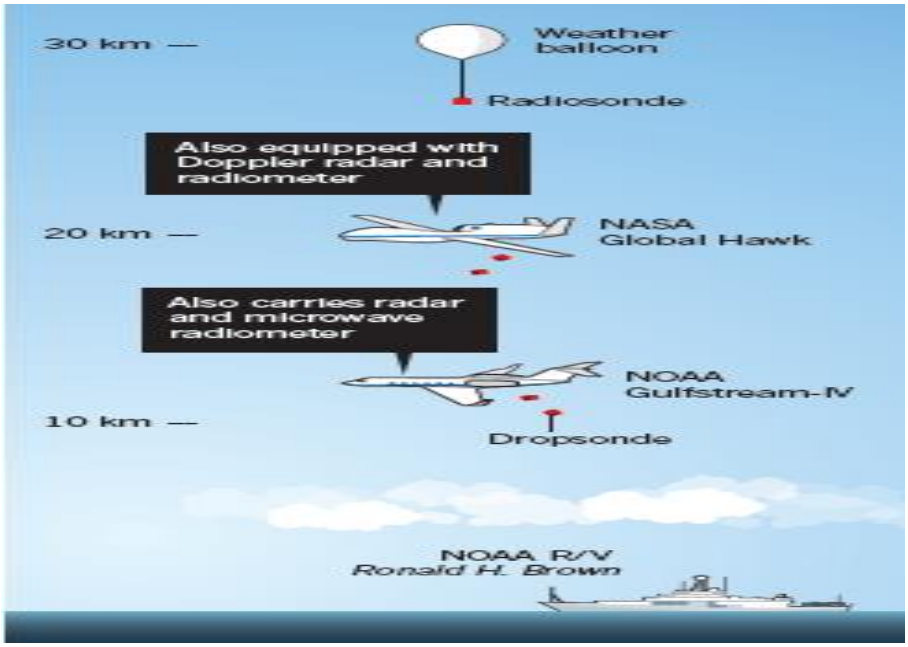

Figure 8: Installation of early warning system for cyclone mitigation

With a properly timed forecast people can be evacuated from vulnerable coastal areas and can be taken to safer communities. Cyclone shelters are one of the most successful means of reducing loss of human lives. Since large-scale evacuations are not always feasible in densely populated coastal areas, community cyclone shelters can be built with buildings used for gathering of a large number of persons, like schools, dharamshalas, hospitals, prayer halls, etc. In order to reduce the impact of the storm, Earth berms and green belts can be used in front of these shelter buildings. Another important mitigation for cyclones involves proper control of Land-use control and planning for human settlement. Major settlement should be done at least 10 km away from the coast.

13.5 Management of landslide

A landslide is the down slope movement of rock, earth, soil or debris. These are caused when when gravitational and other types of shear stresses within a slope exceed the shear strength (resistance to shearing) of the materials that form the slope which occurs commonly by rain, earthquakes, volcanoes, or other factors that make the slope unstable. A land slope has its shear strength which depends mainly on two factors: frictional strength, (resistance to movement between the slope material's interacting constituent particles) and cohesive strength, (bonding between the particles). Natural interlocking of grains in rock and plant roots provides this resisting force. Shear stresses build up in the land slope due to many reasons such as oversteepening of the base of the slopes by natural erosion or excavation, and loading of the slope due to inflow of water, a rise in the groundwater table. Earthquakes and rainstorms are short-term stresses that contribute to the activation of landslides.

Case Study: Malin-Maharashtra Landslide

A massive landslide occurred in the village of Malin in the Pun district of Maharashtra, India on 30 July 2014 (Fig. 8). This landslide was caused by a burst of heavy rainfall; at least 151 people were killed due to it. Heavy rainfall occurred for three days receiving 108 mm (4 in) of rain on 29 July and continuing throughout the following day. The major cause of this environmental destruction is said to be the negligence of geological facts before any developmental process. Deforestation which removes not only trees but also root structures that hold together the soil was a main contributing factor to this landslide. According to experts deforestation was the primary underlying anthropogenic cause of the landslide because it made the soil of the surrounding land loose. Another reason was the change in agricultural practices-Slope development for intensive paddy cultivation, which required leveling of steep areas and hence contributed to the instability of the hills.

Figure 8: Devastation from Malin-Maharashtra Landslide

Mitigation of landslides hence becomes an important step to conserve ecology. Landslides mostly occur at the sloppy lands of mountains. So if we want to stop landslides we need to prevent deforestation and also improve afforestation. This will help the holding of soil particles by plant roots and hence the probability of natural landslides will decrease. Another important step for landslide mitigation includes creation of dry vegetated masonry wall and retaining walls especially on highways. This will provide further resisting force to the soil and rocks of the mountain slopes. Doing no change of topography is also a good way of mitigating landslides. Anthropogenic activities such as construction of buildings, making roads and tunnels, and doing agricultural practices which hamper the slope of mountains do a great harm to the topography of slopes. These individual phenomena join together to generate instability over time, which further leads to heavy landslides. At last the most important step to prevent landslides is doing no change in ground load balance. The resisting forces against the shear stresses should be calculated and anthropogenic activities should be done within its limits so as to maintain the ground load balance and stop the chances for the landslide.

13.6 Chipko movement

Chipko movement was an ecological, social and nonviolent movement which was led to conserve forest and trees. The movement started in 1973 in the village of Mandal of Alaknanda valley in Uttarakhand (then part of Uttar Pradesh) which soon spread to the Indian Himalayas. It was led by Indian villagers specially women who used the tactic of embracing trees to stop contractors from felling them. Chipko is a hindi word and the name of the movement comes from the word "embrace" which means "to hug" or to "cling to".

Figure 9: Women embracing the tree in Chipko Movement.

The root cause for the start of the movement was the development of Uttar Pradesh following the China border Conflict in 1963. There was a great need for infrastructural development which attracted foreign companies whose eyes were on the state's vast forest resources. The industrial logging caused severe monsoon floods that killed more than 200 people in the region in 1970. However, those forest reserves were the lifeline for villagers as they relied on it for both food and fuel. The movement got its spark from the government decision to allot a plot of forest area in the Alaknanda valley to a sports goods company. The villagers were already angered due to the then Government policy which did not allow local agriculturists and herders to cut the trees for fuel or fodder. The angered villagers, especially women, went into the forest and formed a circle around the trees which thus prevented the contractors to cut down trees. The villagers got encouragement and support from environmentalist and Gandhian social activist Chandi Prasad Bhatt, founder of Dasholi Gram Swarajya Sangh, a cooperative organization. The government was forced to cancel the Company's logging permit after many days of agitation.

The movement got its further traction under the supervision of Sunderlal Bahuguna, an eco-activist, who persuaded and educated villagers to protest against destruction of forests and Himalayan Mountains. It was due to his efforts and endeavor that saw the then Prime Minister Indira Gandhi banning deforestation. Sunderlal Bahuguna is best known and remembered for his slogan "ecology is the permanent economy". Another major protest occurred near the village of Reni in 1974, where more than 200 trees were scheduled to be felled. After a large student-led demonstration, the Government summoned the men of surrounding villages, ostensibly to allow the loggers to cut the trees. But, these loggers were met by women of the village, led by Gaura Devi, who refused to go out of the forests and hence stopped the loggers and forced them to withdraw. These events in Reni prompted the state government to establish a committee in order to investigate deforestation in Alaknanda valley. These efforts ultimately led to a 10-year ban on commercial logging in the area.

The Chipko movement is best remembered for the collective efforts made by women who were solely in charge of cultivation and livestock and lost all they had because of floods and landslides which happened due to rise in deforestation in the face of urbanization. Thus sheer survival made women support the movement. Their efforts in the movement helped to conserve and protect forests which also brought about a change in attitude related to their own status in society.

The Chipko movement is an example of transformation from economic struggle to a fight for conservation. It significantly slowed the march of commercial forestry in Uttarakhand and helped in implementation of Forest Conservation Act, 1980.

13.7 Silent Valley movement

Silent Valley movement was a social movement to protect Silent valley reserve forests, an evergreen tropical forest in the Palakkad district of Kerala, India (Fig. 10). It is a 90 km^2 valley surrounded by high ridges. Due to high ridges and thick forest cover, Silent valley is without any human habitation, not even a tribal village. Silent Valley has remained a well-preserved forest because it is difficult to reach there, even on foot.

Figure 10: Silent Valley: A tropical rainforest.

Originally these forests were known as Sairandhri which is another name for Draupadi. The river flowing through this valley, Kunthipuzha gets its name from Kunti (Mother of Pandavas) and puzha which means river. The name 'Silent Valley' was given by the British in 1847 because of a perceived absence of noisy Cicadas. Kuntipuzha river moves from the hills to the plains of Palakkad district. The steep decline in the elevation of the river attracted the people of Kerala State Electricity Board to build a dam over this river. This plan of the Kerala State Electricity Board to begin the construction of a hydroelectric project of 240 MW over the Kunthipuzha in 1976 triggered the Silent valley movement. This project could submerge about 8.3 sq km of untouched moist evergreen forest. The movement caused a wave of protests across the state.

Work was started on the dam in 1976 for which a large number of big trees were felled. The then Prime Minister Indira Gandhi who was very concerned about ecology conservation asked the Kerala State Electricity Board (KSEB) to send reports about how the construction of dam would do no harm to forests in the valley and also appointed a committee to decide if the hydroelectric project was feasible without any significant ecological damage.

The Silent valley movement was supported by a NGO Kerala Sastra Sahitya Parishad (KSSP). The NGO was working to increase scientific knowledge by publishing science texts in Malayalam. The members of the parishad were mostly the teachers of Physics, Chemistry and Biology. Prof. M. K. Prasad, Botany teacher at Calicut College who was also a member of KSSP did the benefit-loss analysis of the dam. In his analysis, he found that due to construction of the dam, a lot of land will get submerged under water and a huge destruction of forests will be made which will make an uneven rainfall distribution. Hence KSSP started to oppose the construction of the dam. The opposition of KSSP was supported by many other environmental organizations of Mumbai as well as other parts of the country such as Dr Salim Ali, an ornithologist. KSSP raised public opinion with membership of 7000 thinking people. It also started a signature campaign, organized street plays, *Jatha* and public debates to discuss the benefits of forests and how building the dam could harm them. Articles were published in the press and students were also involved in the movement.

Lion-tailed Macaque was a species of monkey that was only found in the southern part of Western Ghats. The International Union of Conservation of Nature (IUCN) asked the Indian government to conserve Western Ghats. The pressure created by KSSP and IUCN made the Government of India and then Prime Minister Indira Gandhi to form a joint expert committee under the leadership of Prof. M.G.K. Menon. The committee did a detailed benefit loss analysis of the construction of the dam. Finally, in 1983 Government of India advised Kerala state to abandon the project and in 1985 Silent Valley was declared as National Park. As a result of the great efforts made in this silent valley movement, Western Ghats have been declared now as hotspot and are the last remaining example of flora and fauna that had fully evolved in a Tropical rainforest.

13.8 Bishnois of Rajasthan

The Bishnois are a hindu community , living in western Rajasthan on the fringe of the Thar desert. They follow a Vaishnavite sect and are known from centuries for centuries for sacrificing their lives to protect the environment and conservation of the flora and fauna. These were the nature-loving

people and made wildlife and environment protection a part of their sacred traditions. Right to survive and sharing of all resources by all living beings is the basic philosophy of their religion.

The history of Bishnois dated back to 15th century when Jambhoji, a resident of a village near Jodhpur, had a vision that people's interference with nature caused drought that was faced by the area After these realizations, he became a holy man and came to be known as Swami Jambeshwar Maharaj who laid the foundation of Bishnoi sect in 1485 AD. The word Bishnoi is derived from *Bish* (20) + *Noi* (9). Swami Jambeshwar Maharaj laid down 29 tenets for his followers including a ban on killing animals and a ban on the felling of trees. 7 Commandments were for good social behavior, 10 for hygiene and health practices, 4 for instruction for worship, 2 for good animal husbandry and 6 for environmental protection and compassion for animals. Protection of nature and environment was given the foremost importance in these tenets. Since then, the sect has religiously followed these tenets. Bishnoism teaches love, peace and respect for life, non-violence and harmony amongst trees, animals and human beings.

The Khejari tree which is the most important vegetation in the Thar desert is recognized as a sacred tree by Bishnois. These trees are a source of shade, fodder, edible pods ,fuel wood and also increase the soil fertility. Khejari tree is referred as *Shami* in vedic literature and cutting down and lopping of these is prohibited in Bishnoism.

Among the many stories about how the Bishnois have been beaten up by hunters and poachers for intruding in their area, the sacrifice made by Amrita Devi and over 350 others is a heart-rending example of their devotion. The story comes from a small village Khejarli near Jodhpur, The Maharaja of Jodhpur had a wish to build a new palace for him and he required wood for it. In order to get wood for building a new palace his men went to the area in the morning of September 11, 1730 around the village to fell the Khejari trees. When Amrita Devi came to know about this, she along with her three daughters rushed out to prevent the King's men and hugged the first tree and declared that "Even if she sacrificed her life to save just one tree, it would be a good bargain". Meanwhile, the axe fell on her and she died on the spot (fig 11). The news spread like a wildfire and Bishnois people from 83 surrounding villages rushed to the spot in order to prevent the men from felling the trees. By the end of the day, 363 people sacrificed their lives. After hearing all the incident, the king was filled with remorse and he came to the village and personally apologized to the people. King Abhay Singh honored the courage of Bishnois and also issued a decree engraved on a copper plate: No cutting of trees and hunting of animals within and near Bishnoi villages. This proved the extent up to which Bishnois can go in order to protect wildlife and forests around them.

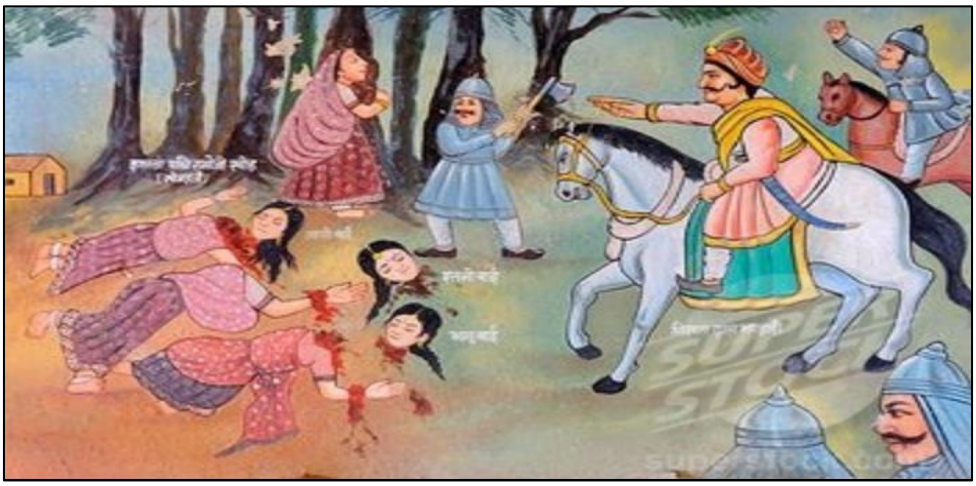

Figure 11: Depiction of great sacrifice made by Amrita Devi

Khejarli sacrifice had a great impact as the Bishnois became the first environmentalists. As a result of traditions followed by Bishnois and their love for nature, the forests near Jodhpur are abundant in trees and wildlife. The forests near Jodhpur harbor the animals mainly antelopes, particularly the blackbuck and the chinkara which are not afraid of humans and can be often seen near the villages eating out of the villagers' hands. The landscape is also greener than elsewhere.

The saying "Sir santhe rooke rahe to bhi sasto jaan" which says that if a tree is saved from felling at the cost of one's head, it should be considered as a good deed. Bishnoism inspired Chipko Movement, 1973, Jangal Bachao Andolan, Bihar, 1982 and Amrita Devi Bishnoi Wildlife Protection Award of MoEF.

Summary

Four important processes involved in management of disaster are: mitigation, preparedness, response, and recovery. For management of flood mitigation strategy by developing and installing better flood prediction and warning systems and using floodplain as fertile land instead for construction of residential and commercial buildings. For management of earthquake we do not have better any reliable warning system, it could be better be managed by zoning of seismically active regions of a nation and constructing building as per requirement suggested by structural engineering. Management of cyclones and tropical storms can best be managed by avoiding irreversible change in climate which could be achieved by approaching net zero emission in future. For current rising incident and severity of cyclone best mitigation options are advanced warning system and associated timely evacuation of community to be affected. Landslides can better be mitigated by avoiding destruction of fragile mountain ecosystems and constructing buildings and highways after careful analysis of resisting and gravity forces. Chipko movement was first started as struggle for controlling forest resources between local community and private businesses and realization of importance of forests in controlling floods and droughts by local community. It was triggered from small incident of deforestation in 1973 in Mandal village of Chamoli district of Uttarakhand where villagers (mostly women) hugged trees for stopping them being cut down by private loggers. Soon it spread in many districts of Uttarakhand and become the cause of enactment of Forest Conservation Act, 1980. Silent Valley movement was another people movement to save valuable tropical forests of Western Ghats. Kerala Sastra Sahitya Parishad (an organization of college and school teachers) played a significant role in saving pristine Silent Valley forest from being submerged in by proposed hydroelectric dam. Not only their efforts stopped the construction of the dam, but Silent Valley was declared a national park which is home to many endemic species. Bisnois, who follow vaishnavite sect based on 29 principles, led one of the oldest environmental movements of India. In their 29 principles six are related to conservation of environment which was formulated by their Guru Jambheshwar since Bisnois was dependent on the very fragile ecosystem of Thar deserts of India. Following these principles, in 1730, Amrita Devi along with 363 other Bisnois sacrificed their lives to save revered Khejri trees in order to protect them from being cut down by employees of Maharaja Abhay Singh of Jodhpur.

Keywords

Environmental ethics, Human virtues, Anthropocentrism, Enlightened anthropocentrism, Intrinsic value, Intra-generational equity, Intergenerational equity, Gender equality, Gandhian way of life, Hindu philosophy of 'Karma', Asceticism, Sustainability, Indian mythology, Venerated trees and plants, Vehicle of god and goddess, Sacred groves, Environmental communication, Psychology of target audience, Effective messaging, Environmental education, Shantiniketan model

Self Assessment

1. Flood risk assessment is done through _____ of river and past flood events.

A. Water quality
B. Aquatic species
C. Dry land
D. Flood plain

2. _____ of hill slopes increases the flood risk.

A. Afforestation
B. Deforestation
C. Dry land

D. Flood plain

3. Tsunami is one of the cause of _____

A. Coastal flood
B. River flood
C. Flash flood
D. Cloud burst

4. Climate change associated _____ is one of the causes of increase of flood incidents.

A. Tectonic plate movement
B. El Nino event
C. Landslides
D. Civil war

5. Epicenter of an earthquake is a _____ of earthquake.

A. Center on surface of Earth's crust which is just above focus
B. Center inside Earth's crust just few kilometers away from focus
C. Circle surrounding focus
D. Focus of energy release

6. Most damaging seismic waves are _____

A. P-waves
B. S-waves
C. Surface waves
D. Water waves

7. Magnitude of earthquake is measured in _____

A. Kilogram
B. Richter scale
C. Joule
D. Watt

8. The abrupt slide of tectonic plates at _____ leads to tectonic earthquakes.

A. Continental crust
B. Mountain peaks
C. Subduction zone
D. Conduction zone

9. Himalaya is most seismically active zone of India since Himalaya is situated at the junction of tectonic plate where _____

A. Pacific plate is plate is subsiding in Eurasian plate
B. Philippine plate is plate is subsiding in Indo-Australian plate

C. Indo-Australian plate is subsiding in Pacific plate
D. Indo-Australian plate is subsiding in Eurasian plate

10. Cyclones originate over _____

A. Polar oceans
B. Tropical oceans
C. Tropical land
D. Mid-latitude oceans

11. The energy for violent wind speed in cyclone comes from _____

A. Core of Earth
B. Solar radiation
C. Cosmic rays
D. Latent heat of condensing water vapor

12. Resisting forces for landslide are provided by_____

A. Tectonic plate movements towards each other
B. Gravitational pull by moon
C. Interlocking of soil organism
D. Interlocking of grains in rocks and plant roots

13. Uttarakhand early forest struggle was for _____

A. Conservation of endangered species
B. Conservation of soil resources
C. Quest of livelihood and dignity
D. Carving out separate state from Uttar Pradesh

14. One of the causes of origin of Chipko movement is _____

A. Flood during monsoon in Kerala in 2018
B. Government's decision to allot a plot of forest area in the Alaknanda valley
C. Flash flood of Uttarakhand in 2013
D. Melting of Gangotri glacier

15. Women of Mandal village (Chamoli district) _____ for stopping contractual logging of forest land during the first protest of Chipko movement.

A. Prepared paintings to save forests
B. Formed sculpture to save forests
C. Formed circle around trees
D. Tide sacred thread around trees

16. Chipko movement led to formation of _____

A. Environmental Protection Act, 1986

B. New state: Uttarakhand
C. Forest Conservation Act, 1980
D. Wildlife Protection Act, 1972

17. Silent Valley movement was to save _____

A. Rainforest of Kerala
B. Rainforest of Meghalaya
C. Himalayan forests
D. Ganga River

18. _____ was one of the causes of Silent Valley movement.

A. Conservation of tiger
B. Conservation of lion-tailed macaque
C. Quest for livelihood
D. Quest for mineral resources

19. Of the 29 tenets of Bishnoism _____for environmental protection and compassion for animals.

A. 10
B. 2
C. 6
D. 1

20. Bishnois revered _____ as sacred three.

A. Peepal tree (Sacred fig)
B. Banyan tree
C. Mango tree
D. Khejri

21. "Amrita Devi Bishnoi Wildlife Protection Award" is given in honor of martyr of _____

A. Chipko movement
B. Quit India movement
C. Khejarli Sacrifice
D. Kargil war

Answers for Self Assessment

1.	D	2.	B	3.	A	4.	B	5.	A
6.	C	7.	B	8.	C	9.	D	10.	B
11.	D	12.	D	13.	C	14.	B	15.	C
16.	C	17.	A	18.	B	19.	C	20.	D

21. C

Review Questions

Q1. What are the general steps involved in management of disasters?

Q2. Explain management of floods.

Q3. Explain the formation of cyclones. What is the best strategy for management of cyclones?

Q4. How does a cyclone affect coastal communities?

Q5. What are the causes of earthquakes?

Q6. What do you mean by focus and epicenter of an earthquake?

Q7. How can we mitigate the impact of an earthquake?

Q8. How can we avoid incidents of landslides?

Q9. Explain causes of Chipko Movement.

Q10. Elaborate role of women in Chipko Movement.

Q11. How 'Kerala Sastra Sahitya Parishad' saved Silent Valley?

Q12. Explain the origin of Bishnoism.

Further Readings

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Unit 14: Environmental Ethics

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Objectives

After completion of this chapter, you will be able to

- know about environmental ethics.
- know how equity is an important concern in environmental ethics.
- understand the role of religions and cultures in environmental conservation.
- know the best practices of environmental communication.
- know the best practices of environmental education (another mode of green communication) to bring about pro-environmental action.

Introduction

Environmental ethics is a branch of philosophy which tries to understand our moral duties towards the environment. The questions like what responsibilities we have towards wild species and ecosystems, what are our obligations towards current and future generations of humans who are dependent on critical ecosystem services, are discussed in a discipline called environmental ethics. It is not just concerned with values related to the environment, but also deals with more concrete issues surrounding societal attitudes, actions and policies needed to protect and sustain biodiversity and ecosystems. Environmental ethics is mostly concerned with:

(1) Rights of individuals that are fundamental to life and wellbeing or intra-generational equity,

(2) Needs of future generation or intergenerational equity,

(3) Rights of other living creatures.

Environmental ethics also helps in deciding which scientific solution (out of two or more available to us) is more ethically or morally sound to solve an environmental problem. For example, to protect humanity from the impact of climate change either we can change our lifestyle and technologies by adding greenhouse gases (GHG) in the atmosphere or we can continue to

accumulate wealth without worrying about anything and use geo-engineering to change the Earth system later to reduce impact of climate change. We need ethical analysis to decide which solution is better to save us from the catastrophic impact of climate change.

We have already discussed many environmental problems and their best and probable solutions such as how we can best manage our natural resources, so human needs could be fulfilled in a sustainable manner, and how we could improve the quality of water we drink or air we breathe. We can achieve both sustainability and minimize human suffering only by implementing best practices discussed till now to increase environmental goods and services. However, implementation of best environmental practices is possible only through participation of each citizen of a community or nation. Environmental communication is a subject which deals with strategies of how to aware and convince the general public, administrators and politicians about scientifically complex details of environmental issues. Environmental communication which is concerned with issues related to environmental problems is actually one of the modes to implement sustainability and other environmental solutions. The other modes for achieving sustainability and a healthy environment are: environmental education, social marketing and public participation. All the four modes of public awareness are collectively called 'Green Communication'. In the second part of the unit, we would discuss the best strategies of environmental communication and environmental education.

14.1 The Basis of Environmental Ethics

One of the bases for judging an action ethical and unethical are the virtues which are needed for flourishing human life. Some of the important human virtues are:

(1) Kindness,

(2) Loyalty,

(3) Sincerity,

(4) Justice,

(5) Honesty

These human virtues are deeply seated in human conscience and a human with a mind free of worldly desire could easily realize and follow these virtues even without any formal knowledge. For example, loyalty and kindness are virtues which could motivate a person to help his/her friend in hardship which could even be realized in a child which has not yet started his schooling. The use of human virtues in deciding a human action (affecting natural ecosystem or biodiversity) ethical or unethical sometimes becomes problematic as human virtues are for human welfare or 'anthropocentric' and does not consider non-human components of Earth. Environmental ethics emerged as a new sub-discipline of philosophy in the early 1970s and posed a challenge to traditional anthropocentrism. It questioned the superiority of human beings to members of other species on earth and tried to assign intrinsic value on the natural environment and its non-human component. This is in contrast to traditional theory of ethics where often human beings are only considered to have any intrinsic value. For example, a person who teaches others has value (called instrumental value) to those who need the knowledge, but he also has value (called intrinsic value) on his own right independent of his value for others. It is difficult to realize the same intrinsic value for non-human components of Earth. The assignment of intrinsic value to non-human components of Earth is called the 'non-anthropocentric' perspective of environmental ethics.

The difficulty in convincing the general public, policy makers and businesses that non-human components of Earth have the same value as humans led to development of environmental ethics based on 'enlightened anthropocentrism'. In enlightened anthropocentrism our duty towards the environment is morally justified as our duty towards human inhabitants of the environment. It is easier scientifically to decide about any activity affecting the environment, whether it would enhance current and future generation welfare, so enlightened anthropocentrism is more pragmatic to decide environmental ethics.[1]

14.2 Intra-Generational Equity

Environmental ethics are concerned with the ways we utilize and distribute natural resources. Is it justified that one individual consumes natural resources in lavish manner in an amount which is many times higher than needed for a standard living while other have barely enough to survive? The simple human virtue of justice requires a more equitable distribution of resources than we encounter at present. Inequality exists at individual, national and global level. There are rich and poor families, rich and poor communities in a country, and developing and developed nations. The current globalization is also widening the disparity between haves and have-nots.

The biomass-based industries such as cotton textiles, paper, plywood, rubber, soap, sugar, chocolate, and other food processing industries depend on resources obtained from rural and wilderness areas. The natural resources shift from wilderness to rural and then to urban areas. Unfortunately, the wealth also moves in the same direction due to non-payment of fair prices of raw materials to tribal and rural peoples and acquisition of their common property resources by industrial and urban sectors. This leads to lavish consumption of natural resources by urban rich, while rural and tribal people struggle to survive. Further, the unsustainable extraction of natural resources mostly due to consumption by urban rich is leading to decline of ecosystem capital.

Poverty resulting from unequal distribution of wealth and access to land also contribute to degradation of the environment as discussed in unit 12 (Human population growth). Lack of sufficient income compels the rural and tribal people to overexploit forest resources to generate enough income, force them to use bio-waste as fuel which leads to increase of air pollution, and living in urban slums leading to pollution of water bodies. The use of warfare for inequality driven social injustices further increases environmental degradation. Hence, to avoid affluence and poverty driven environmental degradation and to achieve sustainability, the equitable sharing of resources is essential.

14.3 Disparity Between Developed and Developing Nations

Environmental ethics are concerned with ownership of resources and their distribution. Most countries rich in natural capitals are found in tropical and subtropical zones of our Earth. Ironically, these are also countries which fall under the middle- and low-income category and are called developing countries. The resources of these countries are exploited by developed countries since developed nations almost exhausted their natural resources and developing nations which lack capital and technologies need investment from rich nations. However, the gain of wealth in developing and developed countries is unequal due to unfair economic practices where low prices are paid for resources (including human resources) used by rich nations to low- and middle-income nations.

The per capita consumption of natural resources is much higher in developed nations than low income or poor nations. The environmental degradation in developing countries due to overexploitation of natural resources is further pushing the marginalized cultures in developing countries towards poverty. To reduce poverty-driven misery of people of developing nations and to save rich tropical ecosystems of developing nations it is required that super rich nations implement fair and just practices in managing world trade. The financial and technological help to natural capital rich developing nations is also a matter of justice.

14.4 Need for Gender Equality

Women especially in rural and tribal regions of India engage in 10-12 hours of hard work every day, often longer than work hours of men. To eke out a living from the environment these women walk long distances to fetch drinking water. They dwell in forests for collecting fodder for cattle and fuel wood for cooking. And it is compulsory for them to cook food for the family including taking care of kids. Most of these works are not even counted in the calculation of GDP of a nation. In addition, women who lost their partner or parent support are often enmeshed in an inextricable cycle of poverty.

As discussed above women of rural and tribal regions are more connected to surrounding natural ecosystems and they understand their value in a much better way. This fact is evident from the often-stronger participation of women in many environmental movements such as the Chipko movement. However, gender bias due to the patriarchal set up of society does not allow women to participate in decision making processes related to management of natural ecosystems.

The gender bias or patriarchy also promotes dualism. Dualistic thinking sees the world in polar opposite terms such as male/female, masculinity/femininity, reason/emotion, white/colored, civilized/primitive, human/animal, culture/nature etc. All the first terms in the above contrasting pairs are considered superior in dualistic way of thinking and they are assimilated with each other. For example, male is associated with masculinity, reason, civilized etc. while the term female is associated with emotion, nature, primitive etc. Dualism confers superiority to everything on male side and promotes "logic of domination" which is the cause of interiorizing and colonizing of women, racism, class exploitation, and ecological destruction.[1]

The promotion of gender equality and feminism is one of the ways to promote conservation of ecosystems as women not only better understand the value of natural ecosystems, but also the promotion of feminism creates a human psychology more inclined towards conservation. Gender equality and empowerment of women is also important in achieving sustainability (Fig. 1) as discussed in unit 12.

Figure 1: Gender equality is needed for sustainable development. (Source: UN Women, Ref. [2])

14.5 Intergenerational Equity

Do we have the right to use all resources of Earth leaving nothing for future generations? This is the ethical question which should be considered when we engage in unsustainable development. We have right to use up all fossil fuels to speed up engine of economic growth as climatic modeling suggest that severe consequences of climate change due rise of GHG (greenhouse gases) would be seen after, say 100 years and till that time we would complete our life span so climate change is not going to affect us severely. Similarly, we can destroy whole tropical forest to harvest timber and extract mineral without worrying about endangered and endemic species which have no market value and let the impact of lack of ecosystem and biodiversity services (productive, aesthetic, information, regulative etc.) to be borne by future generation since they are not present to claim their rights.

Intergenerational equity is needed for sustainable development as it is defined as "meeting the needs of the present without compromising the ability of future generations to meet their own needs". Conserving resources for the future is like putting the interest of future generations ahead of those who are currently suffering from poverty. However, given the choice many people are more inclined to secure a better future for their children and grandchildren by making sacrifices in order to protect a more hopeful future for them. Just as our ancestors have left resources for us, so we have a duty to leave behind the same natural capital to our future generation. We should work as trustees of Earth's natural wealth which is to be handed over to future generations.

14.6 Sustainability and Gandhian Way of Life

Mahatma Gandhi had realized the adverse impact of unsustainable development and consumerism much earlier in a time when problems such as climate change, biodiversity loss was not recognized. He said, "If India wants to be industrialized nation on the line of Britain, then only Indian population would be enough to consume all the resources of world. "As per him:

(1) Men's need but not greed could be supported by our Earth.

(2) Humans are trustees of the lower animal kingdom.

Gandhi promoted simplistic living through his own life (Fig. 2). His view regarding elimination of widespread poverty from India was based on a self-reliant village economy. A prosperous village could be created by conserving and enriching ecosystems surrounding the village and use of indigenous technology based on recycling and use of local resources. He promoted sanitation, handicraft and art-centered education, non-violence and non-exploitative economic practices.[3] Many Gandhian views are also reflected in sustainable development goals (SDG) such SDG 6 (Clean water and sanitation), SDG 12 (Responsible consumption and production) and SDG 8 (Decent work and economic growth).

Figure 2: Gandhism: The way to sustainability.

Essential conditions for prosperity

Let's try to answer the question: Why some countries have undergone rapid development and others have not? One reason is the population growth, but probably the most important reasons relate to the major institutions coordinating social and political life and make up the social capital of a society.

Two essential conditions for development are:

(1) Definition of rights (which could be determined through ethical analysis), and enforcement of those rights.

(2) A socially conscious market-based economy.

To meet the first condition, we need a well-developed body of law, an honest legal system, inclusiveness, broad civic participation and free press. To meet the second condition, we need a functioning communication, transportation system, a viable financial market etc.

History tells us that a nation's meeting above two conditions had made rapid progress in both human resources and produced capital. The nations who failed to attain above conditions are suffering from corruption, inefficiency, banditry, injustice, and intolerance. The outcomes of not being able to meet the above conditions are: poverty and environmental degradation.

The social capital helps in generation of human resources and knowledge assets including produced capital. One of the indicators to measure social capital is the 'rule of law index'.

As per World Bank report Sweden scores 87.5 in the rule of law index, while Pakistan, with its corruption and human rights abuses, scores 33.1. Sweden is a developed country and Pakistan is a developing country. We can understand ethics including environmental ethics are essential for a society to gain prosperity.

14.7 Role of Religion and Culture in Conservation of Environment

The modern discussion in philosophy about environmental ethics for achieving sustainability, conservation and management of wild species, use of geo-engineering to minimize impact of climate change, intrinsic value of nature etc., are also found in traditional value systems of various religions and cultures of the world. Let us discuss a few of the interesting examples.

Hindu philosophy of "Karma"

As per the concept of "Karma " there is the same soul in multiple bodies. Based on "Karma" of a person in present birth, he can take rebirth again as human if he died in excess of ambitious work or *Rajasic Karma*. He would take rebirth as an animal or plant (species ranked lower than human) if he died in excess of bad work like cruel, lazy, foolish work which are also called *Tamasic Karma*. A person can also take rebirth as god in heaven if he died in excess of good work and can spend his/her life in heaven for a time which is based on amount of good work (pity, kindness, honesty, self-less service etc.) or *Sattvic Karma*. So, all animals and plants are actually the same as humans and only because of bad deeds of previous human birth they are forced to take rebirth as species of lower rank. The birth in the form of species of lower rank is considered as punishment or type of imprisonment where a person can get rid of bad deeds of previous work. The plant and animal species cannot do any bad work or *Tamasic Karma*, whatever they do is only service or ecological service.

"Jainism" further extended the concept of one soul to non-living nature such as stones, rocks, water etc. and prescribed strict non-violence or non-injury as one of five doctrines to be followed by a person to achieve salvation. Further, both "Jainism" and "Buddhism" have stressed on asceticism (non-possession and renouncement of sensual pleasure), a thought which was originally taken from Vedic philosophy. The philosophy of non-violence and asceticism clearly promotes the conservation of natural ecosystems. Since religion is deeply seated in people's conscience it could easily be invoked in motivation of society and citizens of nations for conservation of natural wealth. As per Indian philosophy the purpose of human life is not just to accumulate wealth for sensual pleasure, but to realize highest pleasure called salvation through *Sattvic Karma*, which avoids sensual pleasure and does not lead to any violence towards Nature.

Another concept of "Karma Yoga" explained in Bhagavad Geeta promotes equality, an essential condition for achieving sustainability as explained in sections 14.3-14.6. A *Karma Yogi* does not do any work for self pleasure or just for self-satisfaction, but his passion for *Karma* (to do work) is governed by how much happiness he could create for the needy, poor and his/her fellow citizens. He/ She could wish to build his/her business empire to earn billions but only to provide a standard living and happiness to as many people as possible. The "Karma Yoga" is also proclaimed to lead a person to the same salvation as is achieved by asceticism.

The above concept of Hindu philosophy could help in a great way to achieve three-circle sustainability (Fig. 3) as they can provide social justice, environmental conservation and happiness (the purpose of economic prosperity).

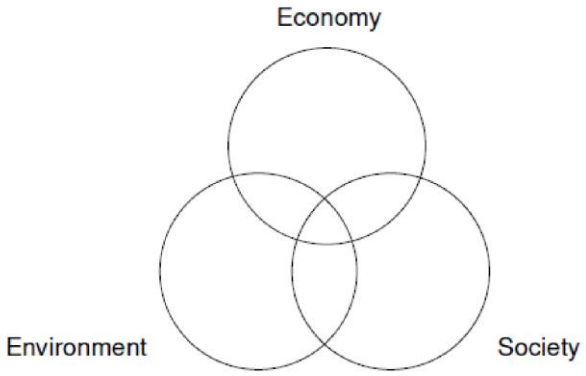

Figure 3: Indian philosophy is well suited to promote "Three circle sustainability".

Species conservation and Indian mythology

As discussed above, the ancient traditional value system of India always valued mountains, rivers, trees, forests and many animals. In this way much of nature was venerated and protected. To convey the importance of non-human components of nature many of the trees, animals, rivers etc.

are described as god or goddess or as associated to them. Some of *trees and plants* which are mentioned in Indian mythology or are venerated in tribal culture are:

(1) Peepal tree (*Ficus religiosa*): The tree is venerated in Hindu philosophy as it is associated with Lord Vishnu. Gautama Buddha, the promoter of Buddhism also got enlightenment under this tree.

(2) Banyan tree: This magnificent tree is also mentioned Indian mythological stories and worshiped in many parts of India once a year. People tied thread around this tree as a symbol of respect.

(3) Mahua tree (*Madhuca indica*): The tree is protected by tribal peoples as it's provides edible flowers (which are also used to prepare alcoholic beverage), and its seeds are used for extracting oil (Fig. 4).

Figure 4: Mahua tree: Venerated tree of tribal.

(4) Tulsi plant: The shrub is grown in almost every home and worshiped as it is linked with Vishnu and Lakshmi. The worship of Tulsi is also linked with worship of one's own ancestor.

(5) Mango tree: Mango tree is also considered auspicious as it is also linked with Lakshmi. Its leaves are used in religious ceremonies.

The *animals* which are venerated in Indian mythology through their association with god and goddess are:

(1) Elephant: It is associated with Ganesh.

(2) Monkey: It is associated with Hanuman who helped King Ram in his war with Ravan.

(3) Cow: A sacred animal which is most loved by Krishna.

(4) Garuda (Big Eagle, See Fig. 5): It's the vehicle of Vishnu as per Indian mythology.

Figure 5: Garuda or Big eagle: Vehicle of Vishnu. (Source: Down to Earth)

(5) Loin: It's a vehicle of Durga, goddess of power.

(6) Owl: It's a vehicle of Lakshmi, goddess of wealth.

(5) Horse: It's a vehicle of the Sun god, Surya.

Dash avatar of Vishnu

Vishnu has taken incarnation in the form of various animals. The incarnation of Vishnu in sequential order is shown in Fig. 6.

Figure 6: Vishnu incarnations associated with animals.

In this way Indian mythology could be a very good tool in promoting the conservation of many key stone species.

Reverence for ecosystems in Indian mythology and cultures

It is not the living species, but whole ecosystems are revered as sacred in Indian mythology and culture. Few examples are mentioned below.

Rivers

In Indian mythology many rivers are given the status of goddess, and they have been worshiped since millennia. These rivers are:

(1) Ganga: It's the most holy river of India and as per the mythology it directly descended from heaven to Earth. The water of Ganga is considered to even purify human intellect.

(2) Yamuna: The river is associated with Krishna who has taken birth at the bank of Yamuna river. The childhood of Krishna is also spent in Gokul village situated at the bank of Yamuna.

(3) Narmada: It is another holy river. As per mythology it originated from the body of Shiva and its sanctity is considered second after Ganga.

The holiness of above rivers in Indian religious thought could be utilized in protection of the whole river ecosystem.

Mountain

Mountain ranges support the fragile ecosystems. In Hindu religious philosophy and in other cultures the whole mountain is considered sacred. The two examples are:

(1) Govardhan Parvat (Hill): This Mountain is situated near Mathura. The whole mountain is worshiped as Krishna used the mountain as an umbrella to save his fellow villagers from severe rainfall.

(2) Mountain in Sherpa culture: Sherpa is a community of Buddhist people which lives in eastern Nepal which is also home of world's greatest mountain Mount Everest. Many of the mountains which are now part of Sagarmatha national park in this Himalayan region are considered sacred by Sherpa as it may anger the deity of the mountain or considered sacred by their Guru Rinpoche. No sentient being could be killed in the areas near the mountain and also few mountains are not even climbed by the Sherpa.[4]

Sacred groves

Sacred groves are forest tracts which are considered the home of deities by tribal people living around the forests. The ecosystem people (people who only use muscle power to process forest resources and live near to these resources) believe that they are part of a big family in which rivers, trees, animals, mountains are also the family members. No human activities are permitted inside sacred groves. In India, sacred groves are found in North-Eastern Hills such as Khasi and Jaintia Hills of Meghalaya (Fig. 7A), in Aravali Hills of Rajasthan, Western Ghats regions of Karnataka and Maharashtra, Central Tract forest of Maharashtra (Fig. 7B), and Surguja, Chad and Bastar districts (part of Central Tract forests) of Chhattisgarh.

Sacred groves are the last refuge of many endangered species. They provide ecosystem services such as clean drinking water, firebreak to communities involved in practice of shifting cultivation.

(A)

(B)

Figure 7: Sacred groves of (A) Meghalaya (Source: Forest and Environment Department, Meghalaya) and (B) Central Tract forest of Maharashtra (Source: Scientific American, Ref. [5]).

From the above discussion it is clear that religious beliefs of Hindu philosophy and tribal cultures have strong scientific basis. Recently, these ideas have given origin to the concept of "Deep Ecology" in environmental ethics. Deep ecology was promoted by Norwegian professor of philosophy Arne Naess. Deep ecology is different from narrow ecology which only talks about problems of environmental pollution, and depletion of environmental resources. Deep ecology promotes integration of human self with nature and considers mankind only a small segment of the great living community of all life forms on Earth. The idea is, "My larger Self is beyond the boundaries of my skin or I am something larger than body and consciousness." The respect and care to my-Self is actually respect and care of the whole nature which is actually a part of me. The idea of deep ecology resonates well with Jainism and Vedic philosophy.

14.8 Environmental Communication

The improvement in the quality of the surrounding environment or achievement of sustainability can only be possible by increasing sensitivity towards the environment among the general public. The citizens who are aware of their right for quality environmental services and their ethical responsibility for the environment can work as vote banks and can create a government inclined towards enhancement and conservation of environmental services. The same enlightened public cans also force corporate and businesses towards implementation of sustainable practices. Now, the question is how we can motivate and inform the general public about pro-environmental attitudes.

There are several tools available for creating public awareness towards the environment. The important ones are: 1. Environmental communication, 2. Environmental education, 3. Social marketing, 4. Public participation. 'Environmental communications' is concerned with mass communication and uses print, electronic and also social media to inform the general public or particular community about environmental issues. 'Environmental education' is concerned with effective teaching of environmental science especially to a level which could be used by students in their future career and in day-to-day life. 'Social marketing' is the use of tools of marketing to change the behavior of the target group or general public for increasing the welfare of the community. Social marketing is not concerned with just increasing corporate profit. 'Public participation' is concerned about how we can engage the general public in national and regional decision making and how the input of the public could be incorporated in Government policies. Here, we would only discuss environmental communication and environmental education in detail.

The purpose of environmental communication is to motivate the general public for sustainable lifestyle and public participation in national environmental policy making, and to force governments and businesses to implement environmental policy effectively. To avoid failure of environmental communication and to achieve the target goal following points need to be properly worked out properly.

(1) Identification of target audience,

(2) Study of psychology of audience,

(3) Development of messages,

(4) Selection of appropriate media,

(5) Delivery of knowledge which could be implemented in action.

Before working on the above mentioned point a communicator should have done a thorough research about the state-of-the-art of the issue and probable obstacle and impact of the goal for which communication strategy is made. The study of environmental issues which affect the target audience and study of their psychology is important. We should be aware of the values and aspirations of the audience. For effective messaging, first we should explain to the audience about how their behavior change can change the environment and how positive change in the environment can help them in achieving things that they value. An emotional connection with the audience and communicator's social influence can help in making communication effective.

Occasionally ego, hedonism and political conservatism may distract the audience to understand the communicator message. In that case helping the audience in realization of universal human values such as justice, unity with nature and broad mindedness can help in promoting pro-environmental action. Let us understand the above points through a case study of implementation of CNG based public transport in Delhi.

CNG implementation in Delhi

In December 1999, Delhi had recorded a 900% rise in the number of Asthma patients compared to December 1998. In addition, the number of premature deaths caused by air pollution had also risen from 7491 in 1991-92 to 9859 in 1995. Delhi was also ranked fourth in the 1990s among the most polluted cities of the world. A public interest litigation (PIL) was filed in the Supreme Court for relief of citizens from air pollution. This prompted the Supreme Court to order the State Government to convert all pre-1990 autos and taxis and 8-year-old diesel buses to CNG powered

vehicles till 1-Apr-2000.[6] With this, one of the biggest CNG conversion programs in the world was launched in Delhi. However, this pro-environmental action was marred with lack of coordination between auto and bus unions, general public, automobile manufacturers, and transport authorities.

The lack of coordination resulted in a sudden reduction of the fleet of buses, autos and taxis on roads of Delhi on 3-Apr-2000.Shortage ofbuses angered local commuters who torched the buses.[7] The overcrowding caused by lack of buses worst affected the school going children and working women. What causes a pro-environmental program linked with improving air quality of Delhi, to violent protest by citizens?

First, no feasibility research was done for implementing the program. Second, two important stakeholders, the general public, bus and auto unions were not motivated regarding the benefits of conversion to CNG. The lack of motivation resulted in delay in placement of order for CNG powered vehicles by bus operators and lack of rise in demand for CNG. Due to this, auto manufacturers did not increase their production capacity and GAIL (Gas Authority of India Limited) had not invested in infrastructure expansion. The third reason was the circulation of biased expert analysis in favor of diesel vehicles. This and pressure from bus and auto unions including petrol pump operators (since they cannot do adulteration in CNG to maximize profit) also encouraged the State Government for inaction.

Above episode shows the failure of environmental communication between different stakeholders. The biggest necessity was the motivation of the target audience, in the given case it was bus and auto unions, by understanding their psychology and aspirations. A careful drafting of messages and their effective dissemination through proper media was essential. Further, the State Government should also be informed regarding obstacles in the implementation of the program.

14.9 Environmental Education

The best way to inculcate sensitivity in young minds towards the environment is environmental education. First of all, we should be aware that everything that we use in daily life, if tracked back to its origin, could be found to be coming from nature. By abusing nature through environmental pollution, ecosystem destruction and unethical distribution of natural resources, one should not expect that nature would continue to support human wellbeing.

To teach young minds about the value of nature and inculcate in them appreciation of beauty and magnificence of nature and motivate them towards sustainable lifestyle; ShantiKetan model of environmental education is one of the most effective one. Let's learn about this model of nature-based education.

Shanti Niketan model

Taking inspiration from the ancient teaching model of India (where learned sagas teach their disciples in an *ashram* situated in forest) Rabindranath Tagore established a school in a beautiful grove of trees in 1901. In Tagore words, "The highest education is that which does not merely give us information but makes our lives in harmony with all existence."

Tagore blended the best of western and traditional educational systems. The curriculum revolved around nature and classes held in nature (Fig 8). The celebration of nature through drama, dance, music and poetry, was also linked with the above model.

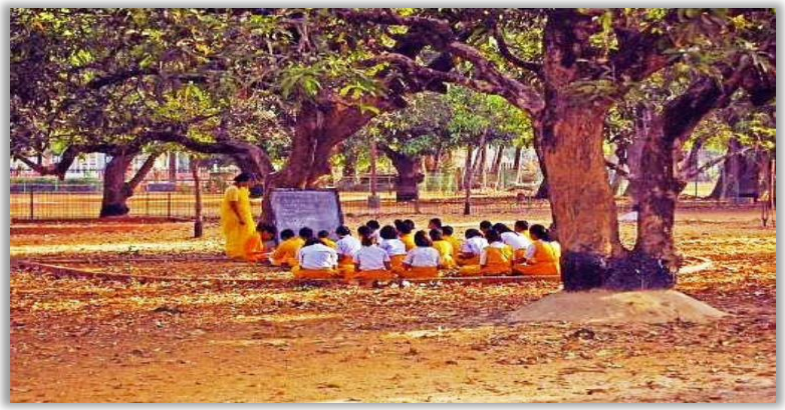

Figure 8: Students studying beneath trees in Shanti Niketan.

Nature walks and excursion is part of education and students are encouraged to keenly observe natural phenomenon such as germination of seeds, lifecycle of incest, birds etc. At Shatiniketan each season is celebrated, and ceremonial tree planting is common. Shatiniketan promoted rural art and culture and rural economy based on locally available natural resources (Fig. 9).

Figure 9: Small mud and coal tar house called Chaitya in Shatiniketan: Sustainable living.

Shatiniketan model is now accepted as best way to teach students environmental education and sustainable living. Surely, understanding nature to find sustainable solution to economic development which can provide standard living and ultimate joy of life to many poor people is difficult, but serenity and magnificence of nature itself can inspire a person to circumvent these difficulties.

Summary

Environmental ethics deals with judgment of morality of human actions affecting the environment. One of the bases of deciding ethics related to the environment is the use of human virtues attached with flourishing human life such as kindness, justice, honesty. Equality (intra-generational, intergenerational, gender) is a very important environmental ethic which is needed to attain sustainability (a state where we survive on interest of natural capital without depreciating it). Intra-generational equity can stop affluence driven overconsumption of resources and poverty driven degradation of the environment. Gandhian way of lifestyle and economic development strongly favors sustainability. The conclusions of ethical discussion of human actions affecting environment or environmental ethics (a branch of philosophy) are similar to discussions of religious philosophy and cultures. The Hindu philosophy of 'Karma' tells us that the same soul is present in all living creatures of Earth including humans. Same human can take birth as an animal or plant based on his 'Karm' in present birth. So, a person should not do anything that destroys the habitat of wild species or harms these species since there are chances that one day he may also be in the body of non-human species. Indian mythology also associates many gods and goddesses to many key-stone species such as lion, monkey, garuda (big eagle), Peepal. The concept of 'Karm Yog' of Vedic philosophy (which explained in Bhagavad Geeta) and asceticism of Jainism and Buddhism spontaneously promotes equality and resource conservation. The worship of sacred groves in many tribal cultures of India further supports the intrinsic value of Nature. Whatever scientific solutions and ethical basis we have for promoting pro-environmental actions can only be implemented by effective use of environmental communication. The analysis of target audience, effective messaging, use of appropriate media and through research on feasibility and impact of goals to be achieved are essential requirements for successful environmental communication. One of the important requirements for improvement of environmental quality is sensitization of common citizens towards the environment. Environmental education is the most effective way to inculcate pro-environmental thinking in young minds. The best way of teaching ethos of valuing nature and sustainable lifestyle is the Shantiniketan model of environmental education.

Keywords

Environmental ethics, Human virtues, Anthropocentrism, Enlightened anthropocentrism, Intrinsic value, Intra-generational equity, Intergenerational equity, Gender equality, Gandhian way of life, Hindu philosophy of 'Karma', Asceticism, Sustainability, Indian mythology, Venerated trees and plants, Vehicle of god and goddess, Sacred groves, Environmental communication, Psychology of target audience, Effective messaging, Environmental education, Shantiniketan model

Self Assessment

1. Our moral duties towards environment are called _____

A. Publication ethics
B. IT ethics
C. Professional ethics
D. Environmental ethics

2. _____ is the ethical foundation of sustainability.

A. Profiteering
B. Consumerism
C. Equity
D. Patriarchy

3. The three circles of sustainability are: Economy, Environment and _____

A. Government
B. Judicial system
C. Military
D. Society

4. _____ is good to for-profit firms, because it can sustain their profit.

A. Fossil fuel driven economy
B. Market based economy
C. Maximum exploitation of natural resources
D. Sustainable economy

5. Life cycle assessment of product assists in resource conservation and lead to _____

A. Unsustainable economy
B. Centrally planned economy
C. Communality
D. Sustainable economy

6. Unequal distribution of natural wealth is cause of _____

A. Prosperous societies
B. Enrichment of environmental services
C. Environmental degradation
D. Social harmony

7. The worst sufferer of movement of wealth from wilderness to rural to urban center, are _____

A. Industrialist
B. Politicians
C. Marginalized societies
D. Middle class

8. Ecological destruction is an extension of _____

A. Feminism
B. Women oppression
C. Women empowerment
D. Oppression of Criminality

9. _____ can help us in achieving inter-generational equity.

A. Gandhian way of life
B. Earning more and consuming more
C. Lavish way of life
D. Business as usual

10. As per concept of "Karma" of Hindu philosophy _____

A. Men are superior to all other living creature including women
B. Human can utilize natural resources as much as they want
C. There are multiple souls in multiple living creatures
D. One soul is present in multiple living creatures

11. The value of river ecosystem are recognized in Hindu philosophy by _____

A. Considering them untouchable
B. Describing their market value
C. Mentioning them as best place for bathing
D. Mentioning them sacred and worship able

12. Environmental communication uses _____ to substantiate or refute arguments related to environmental affairs.

A. Religious belief
B. Scientific research
C. Political conservatism
D. Force

13. _____ and environmental communication are part of green communication.

A. Strategic communication
B. Business communication
C. Environmental education
D. Science education

14. Failure to understand _____ of the target audience is one of the causes of lack of impact of environmental communication.

A. Cast
B. Economic status
C. Religion
D. Psychology

15. The Shantiniketan model is one the best way for _____

A. Subsidy distribution
B. Fashion education
C. Environmental education
D. Good governance

16. _____ is venerated in Indian mythology as the vehicle of Vishnu.
A. Loin
B. Swan
C. Elephant
D. Big eagle (Garuda)

17. _____ are the last abode for many rare animal and plant species in an ecosystem.
A. Tribal village
B. Sacred groves
C. Tribal temples
D. Palm groves

Answer for Self Assessment

1.	D	2.	C	3.	D	4.	D	5.	D
6.	C	7.	C	8.	B	9.	A	10.	D
11.	D	12.	B	13.	C	14.	D	15.	C
16.	D	17.	B						

Review Questions

1. What are environmental ethics? Explain with a few examples.
2. What is the basis of deciding environmental ethics?
3. How intra-generational equality is an ethics related to the environment?
4. Explain environmental ethics of intergenerational equity.
5. How is gender equality ethics related to the environment?
6. How can the philosophy of Gandhism help us in achieving sustainability?
7. How Hindu philosophy of 'Karma' can help us in promoting biodiversity conservation?
8. How do philosophies of 'Karma Yoga' and asceticism promote sustainability?
9. Explain the importance of sacred groves in tribal culture.
10. Elaborate important points for effective environmental communication. Why is mass communication of environmental issues essential?
11. Explain Shantiniketan model of environmental education.
12. How do ethics help in increasing the prosperity of society?
13. What is Deep Ecology?
14. Explain Sherpa culture of sacred mountains?

Further Reading

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