5

ECOSYSTEM

5.1 ECOSYSTEM : MEANING AND CONCEPT

The term **'ecosystem'** was first used by **A.G. Tansley** in 1935 who defined ecosystem as 'a particular category of physical systems, consisting of organisms and inorganic components in a relatively stable equilibrium, open and of various sizes and kinds'. According to Tansley the ecosystem is comprised of two major parts viz. biome (the whole complex of plants and animals of a particular spatial unit) and habitat (physical environment) and thus 'all parts of such an ecosystem-organic and inorganic, biome and habitat-may be regarded as interacting factors which, in a mature ecosystem, are in approximate equilibrium, it is through their interactions that the whole .system is maintained' (A.G. Tansley, 1935). F.R. Fosberg (1963) has defined ecosystem as 'a functioning, interacting system composed of one or more living organisms and their effective environment, both physical and biological'.

According to R.L. Lindeman (1942) the term ecosystem applies to 'any system composed of physical-chemical-biological processes, within a space-time unit of any magnitude'. In E.P. Odum's view (1971) 'living organisms and their non-living (aboitic) environment are inseparably interrelated and interact upon each other. Any unit that includes all of the organisms (i.e. the community) in a given area interacting with the physical environment so that a flow of energy leads to clearly defined trophic structure, biotic diversity and material cycle (i.e. exchange of materials between living and non-living parts) within the system is an ecological system or ecosystem'.

According to A. N. Strahler and A.H.Strahler (1976), 'the total assemblage of components interacting with group of organisms is known as ecological system or more simply, an ecosystem. Ecosystems have inputs of matter and energy, used to build biological structure (the biomass), to produce and to maintain necessary internal energy levels. Matter and energy are also exported from an ecosystem. An ecosystem tends to achieve a balance of the various processes and activities within it'.

Based on the contents of above definitions of ecosystem provided by various scientists it may be pointed out that 'ecosystems are therefore unities of organisms connected to one another and to their environment' (P.A. Furley and W.W. Newey, 1983), 'and the ecosystem is thus the sum of all natural organisms and substances within an area, and it can be viewed as a basic example of an open system in physical geography' (C.C. Park, 1980). Stressing

the importance of ecosystem C.C. Park further says that 'ecosystems are regarded by many ecologists to be the basic units of ecology because they are complex, interdependent and highly organised systems, and because they are the basic building blocks of the biosphere'.

'In a more lucid style and simple term an ecosystem may be defined as a fundamental functional unit occupying spatial dimension of 'earth space ship' characterised by total assemblage of biotic community and abiotic components and their mutual interactions within a given time unit'. (Savindra Singh, 1991)

Properties of Ecosystems

The ecosystems are characterized by the following basic properties :

- Ecosystem of any given space-time unit represents the sum of all living organisms and physical environment.
- It is composed of three basic components viz. energy, biotic (biome) and abiotic (habitat) components.
- It occupies certain well defined area on the earth-spaceship (spatial dimension).
- It is viewed in terms of time-unit (temporal dimension).
- There are complex sets of interactions between biotic and abiotc components (including energy component) on the one hand and between and among the organisms on the other hand.
- It is an open system which is characterised by continuous input and output of matter and energy.
- It tends to be in relatively stable equilibrium unless there is disturbance in one or more controlling factors (limiting factors).
- It is powered by energy of various sorts but the solar energy is the most significant.
- It is a functional unit wherein the biotic components (plants, animals including man and micro-organisms) and abiotic (physical environment) components (including energy component) are intimately related to each other through a series of large-scale cyclic mechanisms viz. energy flow, water cycle, bio-geochemical cycle, mineral cycle, sediment cycle etc.
- Ecosystem has its own productivity which is the process of building organic matter based on the availability and amount of energy passing through the ecosystem. The productivity refers to the rate of growth of organic matter in an aeral unit per time-unit.
- Ecosystem has scale dimension i.e. it varies in spatial coverage. It may be as small as a cowshed, a tree or even a part of a tree having certain micro-organisms. The largest unit is the whole biosphere. Thus the ecosystems may be divided into several orders on the basis of spatial dimension. It is clear that 'the ecosystem is a convenient scale at which to consider plants and animals and their interaction because it is more localised and thus more specific than the biosphere in its entirety, and it includes a sufficient wide range of individual organisms to make regional generalizations feasible and valuable' (C.C. Park, 1980)..
- There are different sequences of ecosystem development. The sequence of ecosystem development in term of a particular suite of physical and chemical conditions is called as **'sere'**. A **'sere'** represents the development of a series of sequential successions starting from primary succession and culminating into the last succession in a sere as **'climax'** or **'climatic climax'** which is the most stable situation of an ecosystem. Thus, the study of ecosystem development may help in environmental planning from ecological point of view.
- Ecosystems are natural resource systems.
- Ecosystem concept is monistic in that environment (abiotic component), man, animals, plants and micro-organisms (biotic components) are put together in a single framework so that it becomes easy to study the patterns of interactions among these components.
- It is structured and well organized system.
- Ecosystem, for convenience, may be studied as a 'black box model' by concentrating on the study of input variables and related output variables while the input variables may be ignored to reduce the complexity.

5.2 TYPES OF ECOSYSTEMS

Ecosystems may be identified and classified on various bases, with different purposes and objectives as outlined below :

(1) On the basis of habitats : The habitats exhibit physical environmental conditions of a particular spatial unit of the biosphere. These physical conditions determine the nature and characteristics of biotic communities and therefore there are spatial variations in the biotic communities. Based on this premise the world ecosystems are divided into two major categories viz. (A) **terrestrial ecosystems,** and (B) **aquatic ecosystems.** There are further variations in the terrestrial ecosystems in terms of physical conditions and their responses to biotic communities. Therefore, the terrestrial ecosystems are further divided into sub-categories of (i) upland or mountain ecosystems, (ii) lowland ecosystems, (iii) warm desert ecosystems, and (iv) cold desert ecosystems. These subecosystems may be further divided into descending orders depending on specific purposes and objectives of studies. (B) The aquatic ecosystems are subdivided into two broad categories (i) freshwater (on continents) ecosystems, and (ii) marine ecosystems. Fresh water ecosystems (Bi) are further divided into (Bia) river ecosystems, (Bib) lake ecosystems, (Bic) pond and tank ecosystems, (Bid) marsh and bog ecosystems while (Bii) marine ecosystems are divided into (Biia) open ocean ecosystems, (Biib) coastal estuarine ecosystem, (Biiic) coral reef ecosystem, or can be alternatively divided into (Biia) ocean surface ecosystems, and (Biib) ocean bottom ecosystems.

(2) On the basis of ecoclines : Ecocline means a broad transition between two different ecosystems of mainly plant communities. Infact an ecocline represents gradient along which biotic communities mainly plant community and abiotic conditions change. The study of ecocline representing the changing conditions, across an ecosystem boundary is known as 'gradient analysis' which implies the plotting of variations of plant community in particular direction and the analysis thereof and division of world ecosystem (M.J. Bradshaw, 1979). Based on above considerations R.C. Whittaker (1970) has drawn four profile diagrams of four ecoclines on a major world scale viz. (A) from Applachians to southern Texas (USA) on the basis of increasing aridity, (B) from equatorial rainforest to desert area, on the basis of increasing aridity, (C) from ground surface to higher altitudes of the Andes on the basis of increasing altitude, and (D) from tropical rainforest to tundra on the basis of decreasing temperature. Thus on the basis of above gradient profiles and associated ecoclines the following types of ecosystems in the aforesaid four situations may be identified :

(A) From mountains with relatively more moisture to the areas of increasing aridity :

(a) mesophytic forest ecosystem, (b) oak-hickory forest ecosystem, (c) oak woodland ecosystem, (d) prairie ecosystem, (e) dry grassland ecosystem, and (d) desert ecosystem.

(B) From the areas of high moisture (equatorial areas) to the areas of lowest moisture (desert) :

(a) tropical rainforest ecosystem, (b) evergreen seasonal-deciduous forest ecosystem, (c) thorn forest ecosystem, and (a) desert scrub ecosystem.

(C) from lower to higher altitudes (in the Andean area of S. America) :

(a) tropical rainforst ecosystem, (b) lower montane rainforest ecosystem, (c) montane rainforest ecosystem, (d) montane thicket ecosystem, (e) elfine woodland ecosystem, and (f) paramos ecosystem.

(D) From equatorial hot and moist areas to cold tundra :

(a) Tropical forest ecosystem, (b)sub-tropical forest ecosystem, (c) temperate deciduous forest ecosystem, (d) temperate mixed forest ecosystem, (e) boreal forest ecosystem, and (f) tundra ecosystem.

(3) On the basis of spatial scales ecosystems are divided into different types of various orders on the basis of spatial dimensions required for specific purposes. The largest ecosystem is the whole biosphere which is subdivided into two major types: (A) continental ecosystem, and (B) oceanic or marine ecosystems. The spatial scales may be brought down from a continent to a single biotic life (plant or animal).

(4) On the basis of uses E.P. Odum (1959) has divided the world ecosystems on the basis of use of harvest methods and net primary production into two broad categories viz. (A) cultivated ecosystems, and (B) non-cultivated or natural ecosystems. Cultivated ecosystems may be further subdivided

into several categories on the basis of cultivation of dominant crops. e.g. wheat field ecosystem, rice field ecosystem, sugarcane field ecosystem, fodder field ecosystem etc. Similarly, non-cultivated ecosystems can be subdivided into forest ecosystem, tall grass ecosystem, short grass ecosystem, desert ecosystem, seeweeds ecosystem etc.

(5) On the basis of source and level of energy : ecosystems can be classified on the basis of source, type and amount of energy available in the ecosystem on the basic premise that the main driving force of the ecosystems for their functioning is energy. E.P. Odum (1975) has classified the ecosystems into four categories on this basis.

(A) **Unsubsidized natural solar-powered ecosystems** are those which are driven by solar energy only wherein incoming solar radiation is used to fix chemical energy. Open oceans, upland forest, wide and deep lakes may be cited typical examples of such ecosystems. The annual energy flow ranges between 1000-10,000 Kcal/m^2/yr (kilocalories per square meter per year) whereas estimated average energy is about 2000 Kcal/m^2/yr.

(b) **Natural-subsidized solar-powered ecosystems** represent tidal estuaries, lowland forests, coral reefs etc. Natural processes like tides, waves, surface runoff, wind etc. supplement solar energy input because these processes bring additional organic matter and bio-geochemical cycles help in recycling of nutrients in the aforesaid ecosystems and thus solar energy is augmented to produce organic matter through primary producers (phtotroph and chemotroph plants) so much so that these ecosystems become the most productive natural ecosystems. The annual energy flow in such ecosystems ranges between 10,000-50,000 Kcal/m^2/year and average estimated energy flow is 20,00 Kcal/m^2/year.

(C) **Man-subsidized solar powered ecosystems** are those where additional energy is supplemented by human activities (e.g. farming). In other words, man applies additional energy in the form of fertilizers both natural and chemical, machines, irrigational water etc. to make the land more productive. Thus he produces more food and fiber crops (food and fibre producing ecosystems) in a simple farming system. In a highly mechanised farming ecosystems, man increases the productivity through the use of chemical fertilizers, pesticides and herbicides (fossil energy to provide additional energy to crops, to kill insects and unwanted plants so that maximum energy is utilized by field crops), irrigational water (which augments the cycling and recycling of nutrients so that these are made available to desired plants), and by developing new hybrid high yielding varieties of seeds so that the plants remain dwarf and require relatively low amount of solar energy and can make maximum use of solar energy to prepare food through photosynthesis and thus can yield more production. The use of machines like tractors, hoes etc. also helps in augmenting the natural processes of bio-geochemical cycles (these agricultural implements make the soil horizons very friable after ploughing and thus organic matter is easily distributed in the soils for easy uptake by plants). The examples of such ecosystems are simple crop and fibre farming systems and highly advanced mechanised farming systems (agriculture) and some forms of aquaculture (fish farming, shellfish cultivation etc.). The annual energy flow is from 10,000 to 50,000 Kcl/m^2/year and estimated average annual quantity being 20,000 Kcl/m^2/year.

(D) **Fuel-powered ecosystems are represented** by urban and industrial areas where fuel energy fully replaces solar energy. The fuel energy is derived through fossil fuels like coal and petroleum which are obtained from underground quite away from the centres of utilization. Besides, energy is also supplied through hydroelectricity, nuclear power and wood coal. These ecosystems are basically wealth generating systems. These ecosystems also generate pollutants and thus are potential sources of environmental pollution in cities and towns, suburban areas, industrial areas as well as the rural atmospheric environment of even very distant places. These fuel-powered urban-industrial ecosystems though generate material wealth of the economy of the society but these depend for life support (oxygen supply and food supply) fully on solar-powered natural ecosystems, nature-subsidized solar-powered ecosystem and man-subsidized solar-powered ecosystems. The annual flow of energy ranges between 100,000 to 3,000,000 Kcal/m^2/year, the estimated average being 2,00,0000 Kcal/m^2/year. Thus these ecosystems are powered by largest amount of energy which comes from non-solar sources.

(6) On the basis of stages of ecosystem development : On the basis of characteristics of

different stages of ecological successions and ecosystem development in terms of community energetics, community structure, life history, nutrient cycling and overall homeostasis (as mentioned by E.P. Odum in his paper 'The Strategy of Ecosystem Development,' 1969) the following four major types of ecosystems are identified :

(A) **Early succession ecosystems** are those which are characterised by high net community production, low biomass supported/unit energy ratio, linear food chain (plants→grazing animals→carnivores), small total organic matter, extra biotic inorganic nutrients, low biotic diversity, short size of organism, simple life cycles, rapid rate of nutrient exchange, unimportant role of detritus in the regeneration of nutrients, undeveloped mutual relationship among community species, poor nutrient conservation, high entropy (disordered biotic community) etc.

(B) **Mature ecoystem** are those which are characterised by low net community production, complex weblike food chain (besides major plants and animals, decomposers also play important roles), large total organic matter, intrabiotic inorganic nutrients, high community diversity, large size of organisms, long and complex life cycles, closed mineral cycles, important roles played by detritus in the regeneration of nutrients, quality production, developed mutual relationships among the community species, good conservation of nutrients, low entropy (ordered structure of communities) etc.

(C) **Mixed ecosystems** represent the overlapping characteristics of early succession ecosystems and mature ecosystems consequent upon general environmental change.

(D) **Inert ecosystems** represent the destroyed ecosystems. These may result from the destruction of either early succession ecosystems or mature ecosystems due to volcanic eruptions or onset of ice ages resulting into complete destruction of life.

(7) On the basis of stability or instability : The concept of stability or instability of ecosystems has been elaborated in different but contrasting ways by various scientists. In a very general sense the stability of an ecosystem is defined in terms of relationships between input and output of matter and energy and functioning of bio-geochemical cycles. An ecosystem in homeostatic or dynamic equilibrium state is that which represents (i) balance in the input and output of energy, (ii) excess of resource pool in comparison to the matter being cycled, (iii) functioning of soils, micro-climate and bio-geochemical cycle as buffers against sudden changes in external conditions, and (iv) minimization of instability due to diversity within the ecosystem. Based on this premise, ecosystems may be classified into (i) simple stable ecosystems, and (ii) complex unstable ecosystems. But this classification is highly controvercial and debatable because there are lot of variations in opinions regarding the concept of system stability. For example, if the stability is defined by frequency of fluctuation of species population, stability has been reported to increase with succession whereas if the stability of an ecosystem is defined in terms of time to be taken for a community to return to its former condition, stability may actually decrease through time (C.M. Harrison, 1980).

5.3 COMPONENTS OF ECOSYSTEM

There are three major components of ecosystems : energy component, abiotic or physical component and biotic component. The abiotic component comprises land and soils, water, air and sunlight. Besides, some organic substances (carbohydrates, protein, fat and liquid substances) and biogenic substances (carbon, nitrogen, hydrogen, phosphorous, calcium and potassium in large quantity and iron, manganese, magnesium, zinc, cobalt in small quantity) are required to sustain life of different biotic communities. Components of the ecosystems have been discussed in detail in the next chapter (Chapter 6).

The biotic components represent plants, animals and micro-organisms. Biotic components are classified into two broad categories on the basis of functions : (i) **autotrophic component** comprises those plants which produce their food themselves through photosynthesis and chemosynthesis. Thus they become (a) **photographs** (which prepare food through photosynthesis by using solar radiation) and (b) **chemotrophs** (which prepare food through chemosynthesis from inorganic substances by oxidation). Autotrophs are the primary producers of the ecosystem. (ii) **Heterotrophic components** comprise those organisms which depend on autotrophs or primary producers (plants). Besides, some heterotrophic organisms decompose and rearrange the organic substances. On the basis of feeding or getting food heterotrophs are divided into 3 sub-

types : (a) **saprophytes** (depending on organic compounds in solutions derived from dead plants and animals), (b) **parasites** (depending on living organisms), and (c) **holozonic** (get food through their mouths, example-large animals including man). The elements of ecosystem are divided into 4 categories on the basis of functions : (i) abiotic elements include abiotic and dead biotic compounds of any site or habitat, (ii) producers (green plants (autotrophs) which act as intermediataries between biotic and abiotic kingdoms), (iii) consumers are primarily animals including man and they obtain their food from organic substances produced by autotrophs or primary producers, and (iv) decomposers are micro-organisms which decompose dead plants and animals and organic substances. During this process they receive their food as well as they rearrange organic substances so that these become easily available to primary producers.

5.4 FUNCTIONING OF ECOSYSTEM

The functioning of an ecosystem depends on the pattern of energy flow because all aspects of living components of an ecosystem depend on energy flow which also helps in the distribution and circulation of organic and inorganic matter within the ecosystem. While the energy flow follows unidirectional path, the circulation of matter follows cyclic paths. These aspects of energy flow and circulations of matter will be discussed in detail in the 8th and 9th chapters respectively. Here, only a brief discussion is presented so as to have a general idea of the functioning of ecosystem.

The energy pattern and flow are governed by first and second laws of thermodynamics. **The first law** states that in any system of constant mass, energy is neither created nor destroyed but it can be transformed from one type to another type (example, electrical energy can be converted into mechanical energy). In terms of ecosystem energy inflow or energy input into the system will be balanced by energy outflow from the system. **The second law** of thermodynamics states that when work is done, energy is dissipated and the work is done when one form of energy is transformed into another form. In the context of ecosystem there is dissipation of energy from each transfer point (trophic level) and thus the dissipated or lost energy is not again available to the ecosystem.

Solar radiation is the basic input of energy entering the ecosystem. The radiant solar energy is received by the green plants. Most of the received solar energy is converted into heat energy and is lost from the ecosystem to the atmosphere through plant communities. Only a small proportion of radiant solar energy is used by plants to make food through the process of photosynthesis. Thus green plants transform a part of solar energy into food energy or chemical energy which is used by the green plants to develop their tissues and thus is stored in the primary producers or autographs at the bottom of trophic levels. The chemical energy stored at trophic level one becomes the source of energy to the herbivorous animals at trophic level two of the food chain. Some portion of energy is lost from trophic level one through respiration and some portion is transferred to plant-eating animals (herbivores) at trophic level two. The transfer of energy from trophic level one (green plants) to trophic level two (herbivores) is performed through the intake of organic tissues (which contain potential chemical energy) of green plants by the herebivores. Thus the chemical energy consumed by herbivores helps in the building of their own tissues and is stored at trophic level two and becomes the source of energy for carnivores at trophic level three. A substantial portion of chemical energy is released by carnivores at trophic level three through respiration because more energy is required for the work to be done by carnivores at trophic level three (building of tissues, growing, movement for grazing, catching prey, reproduction of their offsprings etc.). Some portion of potential chemical energy is transferred from trophic level three to trophic level four or top trophic level represented by omnivores (those animals which eat both plants and animals, man is the most important example of omnivores). The animals at trophic level four mainly man also take energy from trophic levels one and two. Again some portion of energy is released by omnivores through respiration. The remaining stored chemical energy in the plants and animals is transferred to decomposers when they (plants and animals) become dead. The decomposers release substantial amount of energy through respiration to the atmosphere. It may be pointed out that at each trophic level the available potential chemical energy to be transferred to the next higher trophic level decreases as more energy is released through respiration to the atmosphere from each trophic level. Respiration means chemical breakdown of

food in the body and thus respiration releases heat which is transferred to the atmosphere.

Based on above statement it may be summarised that apart from the energy released to the atmosphere through respiration, the remaining energy 'is transferred in successive consumer stages known as trophic (literally nourishment) levels from autotrophs to heterotrops (meaning that they derive their nourishment from others). Ultimately all the energy is passed on the detrivores, or decomposer organisms' (P.A. Furley and W.W. Newey, 1983).

The circulation of elements or matter or nutrients (organic and inorganic both) is made possible through energy flow. In other words, energy flow is the main driving force of nutrient circulation in the various biotic components of the ecosystem. The organic and inorganic substances are moved reversibly in the biosphere, atmosphere, hydrosphere and lithosphere through various closed system of cycles in such a way that total mass of these substances remains almost the same and are always available to biotic communities. 'In other words, the materials that make up the biosphere are distributed and redistributed by means of an infinite series of cyclic pathways motored by the continuous input of energy' (P.A. Furely and W.W. Newey, 1983). The materials or nutrients involved in the circulation within an ecosystem are grouped into three categories viz. (i) **micro-elements** (which are required in large quantity by plants, e.g. oxygen, carbon and hydrogen), (ii) **minor or micro-elements** (which are required by plants in relatively large amounts, e.g. nitrogen, phosphorous, potassium, calcium, magnesium and sulphur) and (iii) **trace elements** (plants require very small amounts of about 100 elements, important being iron, zinc, manganese and cobalt). Besides these inorganic chemical elements, there are organic materials as well which comprise (i) decomposed parts of either alive or dead plants and animals, and (ii) waste materials released by animals. A few of the chemical elements act as organic catalysts or enzymes because they help chemical reactions but seldom undergo chemical change themselves. Such chemical elements are hydrogen, oxygen and nitrogen which belong to gaseous phase (that is they are found in the atmosphere in gaseous state—atmospheric reservoir or pool) and phosphate, calcium or sulphur which belong to sedimentary phase (that is they are found in weathered rocks and soils-sedimentary reservoirs or pool).

Thus these elements, derived from atmospheric and sedimentary reservoirs, are pooled into soils from where these are taken by plants in solution form through the process of root osmosis. The plants then convert these elements into such forms which are easily used in the development of plant tissues and plant growth by biochemical processes (generally photosynthesis). Thus the nutrients driven by energy flow pass into various components of biotic communities through the process known as **'biogeochemical cycles'.** In a generalised form the biogeochemical cycles include the uptake of nutrients or inorganic elements by the plants through their roots in solution from the soils where these inorganic elements, derived from sedimentary phase, are stored. The nutrients are transported to various trophic levels through energy flow. Here the nutrients become organic matter and are stored in the biotic reservoirs of organic phase.

The organic elements of plants and animals are released in a variety of ways i.e. (i) decomposition of leaf falls from the plants, dead plants and animals by decomposers and their conversion into soluble inorganic from, (ii) burning of vegetation by lightning, accidental forest fire or deliberate action of man. The portions of organic matter on burning are released to the atmosphere and these again fall down, under the impact of precipitation, on the ground and become soluble inorganic form of element to join soil storage, while some portions in the form of ashes are decomposed by bacterial activity and join soil storage, (iii) The waste materials released by animals are decomposed by bacteria and find their way in soluble inorganic form to soil storage. Thus, biogeochemical cycles involve the movement and circulation of soluble inorganic substances (nutrients) derived from sedimentary and atmospheric phases of inorganic substances (the two basic components of inorganic phase) through biotic phase and finally their return to inorganic state. The study of biogeochemical cycles may be approached on two scales : (i) the cycling of all the elements together or (ii) cycling of individual elements e.g. carbon cycle, oxygen cycle, nitrogen cycle, phosphorous cycle, sulphur cycle etc. Besides, hydrological cycle and mineral cycles are also included in the broader biogeochemical cycles.

community because exposed surface due to deforestation is subjected to intense weathering and erosion and nutrients are washed out by surface run-off. Himalayan forest ecosystem is a typical example of ecosystem instability because mass deforestation and subsequent grazing have resulted into complete removal of forests at certain localities.

The factors responsible for ecosystem stability or instability should always be viewed in terms of ecosystem resilience. If the environmental changes exceed the ecosystem resilience, ecosystem instability is caused but when the ecosystem resilience is such that it can withstand the environmental changes, ecosystem stability is maintained. The environmental changes which are responsible for ecosystem instability are both natural ones (climatic change, for example) or man-induced.

Man causes instability in the natural ecosystem by :

- destroying completely or partly the natural vegetation or original animal species or by replacing them by other vegetation or animal species;
- introducing exotic plants or animals or both to any area where such biotic communities were not present previously;
- altering or modifying one or more components of physical environment (such as land use changes);
- introducing foreign chemical substances through the use of chemical fertilizers, pesticides and herbicides;
- increasing or decreasing the original proportion of atmospheric gas i.e. by changing the atmospheric chemistry e.g. emission of greenhouse gases and ozone depletion;
- manipulation of environmental processes etc.

Man has modified many of the natural ecosystems and hence has disturbed the stability of ecosystem and ecological balance through fast rate of urbanization and industrialization, mechanization of agriculture, alarming rate of deforestation etc. Most of the forest ecosystems right from the rainforests of Amazonia to mountain forests in all the climatic regions have been degraded due to reckless felling of trees. The freshwater terrestrial ecosystems such as rivers and lakes have been greatly polluted due to immense volume of sewage water, coming from the urbaan and industrial sectors, discharged into rivers and lakes. Managed ecosystems such as farmlands have been destabilized due to heavy irrigation and excessive use of chemical fartilizaers and herbicides. The temperate grassland ecosystems (such as Steppes, Praries, Pampas etc.) have been entirely changed by removing natural grasses and other vegetation and have been changed into farmlands. Many more examples may be cited to demonstrate the impacts of human activities on stability/instability of ecosystems. (see chapter 3 and 15 for further reading materials on this theme).