M.Sc. Final Year
Zoology, Paper - II

LIMNOLOGY

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MADHYA PRADESH BHOJ (OPEN) UNIVERSITY – BHOPAL

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SYLLABI-BOOK MAPPING TABLE

Limnology

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INTRODUCTION

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Limnology is the study of fresh or saline waters contained within continental boundaries. Although many limnologists are freshwater ecologists, physical, chemical, and engineering limnologists all participate in this branch of science. Limnology covers lakes, ponds, reservoirs streams, rivers, wetlands, and estuaries, Limnology evolved into a distinct science only in the past two centuries, when improvements in microscopes, the invention of the silk plankton net, and improvements in the thermometer combined to show that lakes are complex ecological systems with distinct structures.

Primary objective of limnology is to understand the causal mechanisms operating in and controlling our natural world. It is a because of the premier importance of fresh water for the well-being of humankind. The greater our understanding, the higher the probability to predict accurate patterns of events within aquatic ecosystems in response to human manipulations and disturbances.

Under the term inland waters are included all kinds or types of water - running or standing; fresh, salt or other physicochemical composition which are wholly or almost completely included within the land masses. Causal influences involve various factors - physical, chemical, biological, meteorological, etc., which determine the character and quantity of biological production.

Freshwater systems - lakes, wetlands, rivers and streams, have been critical to the establishment of civilizations throughout human history. From ancient times, civilizations have been established based on their proximity to water. Water bodies are essential to humans not only for drinking but also for transportation, agriculture, energy production, industry and waste disposal. Contaminated runoff from expanding urban and agricultural areas, airborne pollutants and hydrologic modifications such as drainage of wetlands are just few of the many factors that continue to degrade surface waters. Determining which of these factors has the most significant influence on the quality of a water body requires knowledge about the interaction of the water body with its watershed and how the various inputs affect its physical, chemical and biological characteristics. One of the critical sciences required to understand these aquatic ecosystem interactions is called limnology.

This book is divided into four units that helps the students to know the basic concepts of physical limnology, chemical limnology, biological limnology and Water management. The book follows the Self-Instructional Mode or SIM format wherein each unit begins with an 'Introduction' to the topic followed by an outline of the 'Objectives'. The detailed content is then presented in a simple and structured manner interspersed with Answers to 'Check Your Progress' questions. A list of 'Key Terms', a 'Summary' and a set of 'Self-Assessment Questions and Exercises' is also provided at the end of each unit for effective recapitulation.

UNIT 1 PHYSICAL LIMNOLOGY

NOTES

Structure

1.0 INTRODUCTION

The term 'Limnology' is derived from Greek word; *Limne* means lake and *logos* means knowledge and is defined as "The Study of Inland Waters' (running and standing waters, fresh and sometimes saline water; natural or manmade water). Limnology is a branch of science that deals with the study of the biological, physical, chemical, geological, hydrological aspects of an aquatic ecosystems especially of lakes, reservoirs, ponds, rivers, wetlands, and groundwater. Limnology can also be defined as the scientific study of the world's inland water bodies such as lakes, artificial reservoirs, rivers, ponds, wetlands, saline lakes, and coastal bays and wetlands. A more recent sub-discipline of limnology, termed landscape limnology, studies, manages, and seeks to conserve these ecosystems using a landscape perspective, by explicitly examining connections between an aquatic ecosystem and its drainage basin. Recently, the need to understand global inland waters as part of the 'Earth System' created a subdiscipline called global limnology. This approach considers processes in inland waters on a global scale, like the role of inland aquatic ecosystems in global biogeochemical cycles.

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Limnology is the integrative, multidisciplinary, scientific study of inland waters. Limnology is built on subdisciplines, including geology, physics, chemistry, biology, and often adopts an ecosystem perspective to address both academic and applied problems. The science of limnology is broad in scope and covers all inland water systems, such as lakes, reservoirs, streams, rivers, wetlands, and ground waters.

Physical limnology is focused on water movement at all spatial scales (from large-scale water balances to turbulence); heat and gas transfers; the optical properties of water, and often, the effects of physical properties on chemical reactions or organism function, and vice versa. Major threats of the warming climate for aquatic systems include quick changes in the seasonal ice cover and thermal stratification of lakes. The physical limnology deals with quantification of these changes and estimation of their consequences for aquatic ecosystems by considering the wide spectrum of abiotic processes in lakes.

Physical properties of aquatic ecosystems are determined by a combination of heat, currents, waves and other seasonal distributions of environmental conditions. The morphometry of a body of water depends on the type of feature, such as a lake, river, stream, wetland, estuary, etc., and the structure of the earth surrounding the body of water.

In this unit you will study about the basic concepts in Limnology, scope of limnology, various fresh-water environment and their types, freshwater ecosystems and their limiting factors, origin, classification, distribution and ecology of lakes, classification, form, zonation and ecology of streams and ponds.

1.1 OBJECTIVES

After going through this unit you will be able to:

- Understand the basic concepts in 'Limnology'
- Define the scope of limnology
- Elaborate on the various types of Fresh water environments
- Analyse the limiting factors of freshwater environment
- Comprehended about lakes their origin, classification, zonation and ecology
- Explain the origin, classification, zonation and ecology of streams
- Understand the ecology of springs
- Explain the origin, classification, zonation and ecology of ponds

1.2 BASIC CONCEPTS AND SCOPES OF LIMNOLOGY

The term Limnology was coined by Francois-Alphonse Forel. Limnology is referred to as a division of ecology or environmental science. The term Limnology is derived from Greek word; *Limne* means lake and *logos* means knowledge and is defined as 'the study of inland waters' (running and standing waters, fresh and sometimes saline water; natural or man-made water). The term inland waters included all

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kinds or types of water – running or standing; fresh, salty or with other physicochemical composition which are wholly or almost completely included within the land masses. This includes the study of lakes, ponds, rivers, reservoirs, swamps, streams, wet lands, bogs, marshes, etc. Hence, it is commonly defined as that branch of science which deals with biological productivity of inland waters and with all the causes responsible for determining it (Welch, 1963).

Our inland waters are vital and important resources. They provide us with drinking water, recreation, bird and wildlife viewing, fishing, land protection, and so much more. Limnology is the study of inland waters and their many different aspects. The word comes from the Greek *limne,* which means marsh or pond. But limnology is so much more than that. Limnology covers all inland waters, which may be lakes, rivers, and streams, but also reservoirs, groundwater, and wetlands. These are often freshwater systems, but limnology also includes inland salt and brackish, or slightly salty, waters

Proper management is required for better utilization of existing resources in lakes, rivers, and reservoirs. In many countries, the construction of landscaping dams has resulted in significant changes in natural aquatic and terrestrial ecosystems, creating new ecosystems with unique features. These ecosystems can be managed for a variety of purposes with little investment through the application of basic knowledge. It can also perform important practical functions in limnology by increasing scientific interest and basic knowledge.

It is important to emphasize that limnology correctly encompasses an integration of physical, chemical, and biological components of inland aquatic ecosystems of the drainage basin, movements of water through the drainage basins, and biogeochemical changes that occur en route, and within standing (lentic) waters. The lake ecosystem is a system that is intimately coupled with the land surrounding it in its drainage area and its running (lotic) waters that transport, and metabolize en route, components of the land to the lake.

Inland waters are diverse and fascinating places. Limnologists, or those who study limnology, need to be familiar with many different aspects of inland waters and their relationships with other water systems, including our atmosphere. For example, limnologists may study:

- Water flow
- Oxygen in the water
- Food web dynamics
- Animal movement patterns
- Minerals and other water chemicals
- Pollution
- Ecosystem structure
- The economics of water
- Light influences
- Nutrient cycles

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- Plants that live on, in, or near inland waters
- Sediments
- Bacteria
- Human influences
- Ecosystems
- Animal communities

Physical limnology deals with the physical properties of freshwater bodies like lakes and rivers. Studying physical limnology includes changes in light levels, water temperatures as well as water currents. Water absorbs energy from sunlight, which keeps the surface water warm. As the sun's intensity, changes throughout the year, the amount of heat absorbed in the summer is much greater when compared to heat energy absorbed in the winter season. During the summer season, lakes become stratified or layered, with the warmer, lighter water floating on top of the cooler, deeper water. In the winters, the surface of the lake loses its heat and mixes with the cooler waters present below. Understanding the cycle of mixing and stratification is enormously essential for a better understanding of the biology of flora and fauna existing in the freshwater bodies.

1.2.1 Scope of Limnology

Limnology is referred to as a division of ecology or environmental science. The term Limnology is derived from Greek word; *Limne* means lake and *logos* means knowledge and is defined as 'The Study of Inland Waters' (running and standing waters; fresh and sometimes saline; natural or man-made water). Limnology is considered as an interdisciplinary science that integrates several scientific disciplines like life sciences, earth sciences, geology, zoology, botany, meteorology, physics, chemistry as well as mathematics into one. Limnologists are scientists who study the regional waterways as well as freshwater ecosystems, conducting the chemical analysis and taking plant and water samples to understand their ecological impact. Limnologists majorly focus on freshwater, although some work with inland bodies of brackish or salt water. Limnologists observes and reports various organisms in an aquatic system ranging from small microscopic animals to large creatures like water bears present within an aquatic system. They regularly generate models to help to predict how the water systems under observation will function at given conditions.

Limnologists are expected to have at least a master's degree, however other positions in the field of limnology will require a doctorate degree. The employment opportunities range from options like teaching in an academic institution, scientist position, research opportunities within a private or government aquatic research centres as well as working with the environmental government agencies. Limnologists employed by academic institutions may teach courses on such environmental topics as ecosystems analysis, conservation of aquatic resources as well as water science. They may also conduct research projects on environmental issues, avail grants in support of their research, conduct laboratory experiments,

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and do field work. Government agencies, universities and research companies employs limnologists to monitor the health of the regional water environments. Limnologists evaluate the impact of anthropogenic activities, as well as other biotic and abiotic factors on the current and future health of regional waterways. They conduct numerous tests like water sampling, chemical analysis and biological monitoring to determine if pollution from manufacturing, farming, or recreational activities have negatively impacted the health of an area. Limnologist may also interact with politicians in establishing guidelines as well as policies,which may be utilized during times of crisis like after a pollution event or catastrophic storm. Limnology is a broad subject encompassing many different aspects of other sciences and studies like freshwater ecology. As the name suggests, it deals with the studies related to freshwater ecosystem like physical, chemical and biological properties of the freshwater aquatic system; nutrient cycling in freshwater ecosystem; abiotic and biotic factors influencing the freshwater ecosystem. Another large branch of limnology is freshwater biology. Limnologists in this branch deals with the microscopic and macroscopic organisms present in freshwater system. They keep records on environmental changes, and maintain a catalogue of the biological organisms found in their assigned region. Freshwater biology is different from freshwater ecology as it focuses primarily on the organisms present in it and not the entire environment.

To conclude, limnology can be a good career choice for people who relish field work. Many limnologists spend majority of time in the field collecting samples as well as making observations and periodically returning to their laboratories to conduct tests and catalogue the organisms that they observe in the aquatic system.

1.3 FRESH-WATER ENVIRONMENT

Freshwater habitats occupy a relatively small portion of earth‘s surface as compared to marine and terrestrial habitats. As depicted in the figure, 97% of the earth’s water is in the oceans or sea as is referred to as saline water. Only 3% of the water present on the continents is freshwater. Sea water or saline water cannot be used for drinking or household purposes. Thus, we depend heavily on freshwater sources for carrying out day to day life activities. Figure 1.1 depicts the distribution of water on earth’s surface.

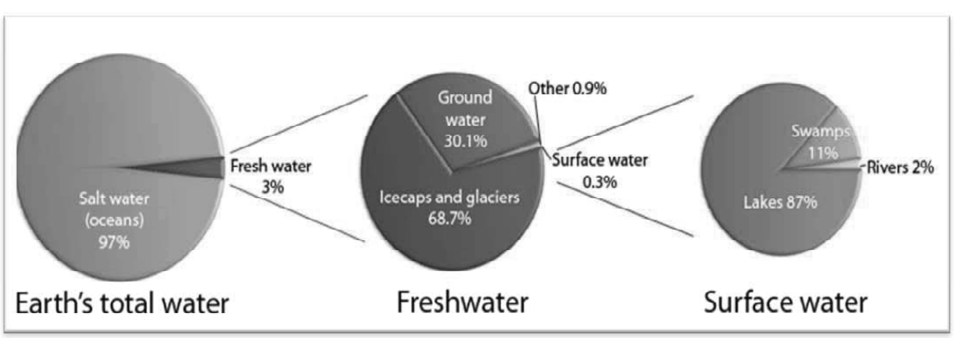

Fig. 1.1 *Distribution of Water on Earth’s Surface*

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However, they play a far more important role for humans due to following reasons:

- Every living entity on earth-be it plants or animals needs water for carrying out its metabolic process.
- Freshwater serves as the habitat for several plant and animal species.
- It acts as major life support system for living organisms.
- It is major abiotic element on earth.
- It fulfils household needs.
- Recreation activities.
- Industrial and commercial purpose like in paper industry.
- Electricity generation in hydroelectric power plants.
- Agricultural activities like irrigation, animal feeding operations
- Medical activities like in haemodialysis, dental procedures

Freshwater habitats are studied under three major categories for convenience:

1) Lentic water (*lenis,* calm) or Standing water: For instance: Lake, pond, swamps, etc.
2) Lotic water (*lotus,* washed) or Running water: For instance:- spring, streams, rivers, etc.
3) Wet Lands: Marshes and swamps.

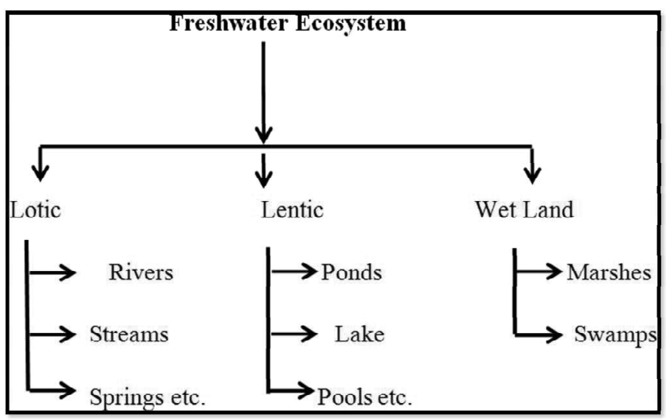

Fig 1.2 *Different Types of Fresh Water System*

1. Lentic Water System

Lentic aquatic systems contain stagnant waters. Lentic water system is closed system, i.e., they are formed in small or large depressions on earth's surface which possess no exit for the water to flow out. The material inside the lentic water system has no exit, i.e., it has to decay, decompose or persist as such within the lentic body only. Ponds and lakes are the best examples of such systems. A lentic aquatic body exhibits zonation with each zone having its own characteristic properties. The littoral zone- is known as the shore area of the lentic water body and allows easy penetration of the light; Limnetic zone represents the zone of open waters which are deeper as well with the presence of plenty of light that promotes active photosynthesis as well as growth of free floating autotrophs; Profundal zone also known as aphotic zone receive very less light when compared to euphoric, i.e. , both littoral and limnetic zone; Benthic zone is the bottom most zone having plenty of heterotrophic organisms depending upon dead and decaying matter from above zones. The marked difference in the lentic and lotic water system is due to the absence of flow in lentic water system.

Lentic systems derive most of their waters from rains, surface runoffs or from underground sources. Physicochemical characteristics of water are quite stable. Physiochemical properties of the water changes with the season and so is the productivity of the lentic water body. Flora and Fauna residing in the lentic body fluctuates with the season. Periods of bright sunshine are usually found associated with a rich growth of phytoplankton and a remarkable lowering of the concentration of a number of plant nutrients. Total surface area of lentic water body is a more essential factor in determining the overall produc-tivity of the system rather than total volume of the water or the depth of the water body. The zone receiving the light. i.e., Littoral and Limnetic zone determines the amount of productivity. There could be enormous volume of nutrient rich water in profundal zone or the benthic zone however these zones, in the absence of sunlight are least productive. Thermal stratification and stratification of oxygen causes different layers of a lentic water to have different oxygen content and nutrient status. The temperature of its surface layers is directly influenced by atmospheric temperatures and the presence or absence of air circulation. The deeper layers are not affected much by atmospheric temperature as they are insulated from all sides. Figure1.3 is depicting the lentic ecosystems.

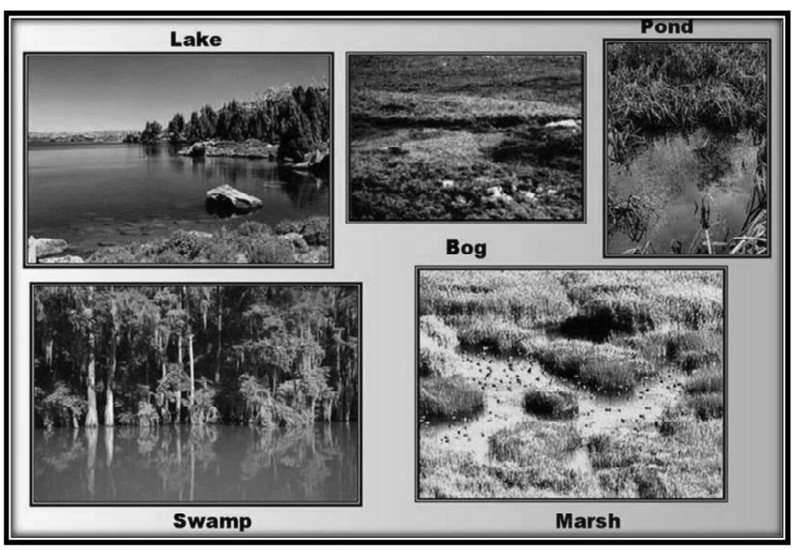

Fig 1.3 *Lentic Ecosystems*

2. The Lotic Aquatic Systems

Lotic aquatic systems contain free flowing waters. Streams as well as rivers are familiar examples of lotic systems. The primary role of these lotic bodies of water is to carry the surplus rain water back to the sea. Water in a lotic system is derived from diverse sources. The flow of water is unidirectional in a lotic water system.

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The water keeps on flowing in narrow channels, which are not so deep when compared to lakes. The bottom of a lotic body continuously adds and receives materials from the mass of water above. The velocity of water in the lotic system keeps on changing due to the fluctuations in the volume of water present in the lotic system. The water level too keeps on changing in a lotic water system. Water in a lotic system acts as an effective agent of transfer, transport as well as dilution. The free-flowing water in a lotic water system keep on eroding materials all along their channels and depositing them elsewhere. There is a thorough mixing of contents in a lotic aquatic system. Stratification and stagnation are altogether absent in a lotic water system. The physio-chemical parameters of water quality in a lotic water system keeps on changing. There is no stability in the environment of a lotic aquatic system as compared to that of lentic water body. Plenty of oxygen is derived from evenly distributed air present throughout the water mass. Oxygen is also added to the lotic water system by autotrophs. Oxygen depletion is, therefore, rare in unpolluted lotic waters. Due to the presence of limited flora and fauna in lotic water system, nutrient depletion is rare. Turbidity prevents or limits the penetration of light to deeper zones of lotic systems. The amount of carbon dioxide present is very less in a lotic water system. Due to limited availability of light as well as carbon dioxide the productivity of a lotic water system is low. Productivity is generally low in rapidly flowing waters; however, it keeps on increasing/rising as the velocity of the water keeps on going down. Large crops of algae and other organisms rarely develop in moving waters. Area and depth show little correlation with productivity in lotic waters. There is little correlation between physicochemical characteristics of the aquatic environ-ment and the productivity of the system. Presence of flowing water or water current is the main feature of a lotic system. Those organisms (both flora as well as fauna) which have effective mechanism to stay at one place in the flowing waters can thrive well in these systems. Both flora as well as fauna uses water currents to disseminate their seeds, spores and other reproductive structures throughout the length and breadth of the channel. Similar species may occur throughout the entire course of a stream or a river. Figure1.4 is depicting the lotic aquatic systems.

Fig 1.4 *Lotic Aquatic Systems*

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3. Wetlands

Wetlands are referred to as the ecotones or transitional zones between permanently aquatic and dry terrestrial ecosystems. According to Ramsar Convention (Article 1.1) wetlands are 'Areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary with water, that is static or flowing, fresh, brackish or salty, including areas of marine water, the depth of which at low tide does not exceed six meters'. In addition, for the purpose of protecting coherent sites, the Article 2.1 provides that wetlands to be included in the Ramsar List of internationally important wetlands: 'May incorporate riparian and coastal zones adjacent to the wetlands, and islands or bodies of marine water deeper than six metres at low tide lying within the wetlands'.

A wide variety of wetlands like marshes, swamps, open water bodies, mangroves, tidal flats, salt marshes, etc., exists in our country. Wetlands are vital to maintain a healthy environment.

1.3.1 Freshwater Ecosystems- Limiting Factors

1. Temperature as a Limiting Factor in Freshwater System

Temperature of water bodies varies from place to place with time due to changing atmospheric conditions. Temperature of water ranges anywhere from 0 to 100 degree Celsius. It is measured using thermometers. The temperature keeps on decreasing gradually from the surface to the bottom of the water body.

Temperature fluctuations produces typical patterns of circulation as well as stratification within the water bodies. On the basis of tolerance to temperature, organisms can be classified as stenothermal and eurythermal organisms. Eurythermal organisms are those organisms which can withstand a wide range of temperature, whereas stenothermal organisms are those organisms that only survive in a narrow temperature range. Therefore, even a small change in temperature can have widespread effects especially on stenothermal organisms.

2. Turbidity as a Limiting Factor of Freshwater System

Turbidity refers to the measure of relative clarity of a liquid. It is an optical characteristic of water and is a measurement of the amount of light that is scattered by material present in the water, when a light is passed through the water sample. Turbidity is directly proportional to light scattered, i.e., higher the intensity of scattered light, higher is the turbidity of water. The material that increases the turbidity of water includes slit, tiny organic matter, inorganic material, clay, plankton, dissolved matter as well as other microscopic organism. Higher turbidity makes the water cloudy or opaque. In fact, turbidity of the water is an indicator of potential pollution present in the water bodies. Excessive turbidity, cloudiness or opaqueness in drinking water is not only unappealing, but also unhealthy. High turbidity can provide habitat for pathogens which may lead to outbreak of water borne diseases.

As mentioned above, turbidity of water directly influences the penetration of light. It limits the penetration of light in the aquatic bodies. Productivity of the fresh water system depends upon the penetration of the light. For instance: Large shallow lakes tend to be more productive when compared to lakes with deep water as more light reaches the lake bed. In larger rivers, the canopy is open which allows the algal production.

3. Water Current as a Limiting Factor in Freshwater Ecosystem

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Current also a significant role in estimating the distribution of salts, vital gases as well as minute organisms. It acts as an essential limiting factor for the lotic systems particularly for streams.

4. Concentration of Respiratory Gases, i.e., Oxygen and Carbon-Dioxide as Limiting Factor in Fresh-Water Ecosystem

The concentration of two gases namely oxygen and the carbon dioxide usually acts as limiting factor for organisms residing in freshwater system. Dissolved oxygen content (DO), Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD)are the important determinants for measuring the biological and physical health of a water body. Dissolved Oxygen (DO) is the amount of oxygen that is present in water. Water bodies receive oxygen from the atmosphere and from aquatic plants. Running water, such as that of a swift moving stream, dissolves more oxygen than the still water of a pond or lake. As mentioned above, Oxygen gas is absorbed by the water from the atmosphere but it is being consumed by organic matter present in it. Therefore, if the oxygen gas present in water is less than its normal saturation level, it indicates the presence of organic matter which makes the water unsuitable for consumption. The amount of organic matter present in the water can be assessed by supplying oxygen to the water sample under observation. The organic matter present in water will start consuming the oxygen and undergoes oxidation. Thus, Biological Oxygen Demand (BOD) or Biochemical Oxygen Demand (BOD) is referred as the amount of oxygen needed or demanded by aerobic microorganisms to break down the organic matter present in a certain sample of water at a specific temperature over a given period of time. BOD of water sample is evaluated by measuring the oxygen consumed by the bacteria from the decomposition of organic matter over a period of five days at a specific temperature of 20 degree Celsius. A lot of factors influence the BOD of water like temperature, pH of the water sample, inorganic substance present in the water, kind of aerobic microorganisms present in water, amount and type of organic matter present in the water sample, etc., BOD values indicate the polluting potential of water. A BOD value of less than 1mg/L indicates pure drinking water, BOD value between 2-8mg/L indicates moderately polluted water whereas a BOD value greater than 8mg/L indicates severely polluted water unfit for consumption. BOD finds its prime significance in sewage treatment plants. It indicates the respiration rate in sludge, soil, garbage, etc., The Chemical Oxygen Demand (COD) represents the amount of oxygen necessary for the aerobic biological oxidation (breakdown) of the organic substances in a given water body or sample to carbon-dioxide (CO_2) and water (H_2O) if the organics are actually biodegradable. COD measurements are important in accessing the quality of a given water body. COD values helps us to determine the extent of pollution that the water has undergone. COD tests also assess the amount of inorganic contaminants that is dissolved or suspended in a water body. Thus, it can be concluded that higher the COD, higher is the contamination level of water. The COD test usually involves a very strong

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oxidizing chemical agent like potassium dichromate ($Cr_2O_7^{2-}$). The primary basis for the COD test is that nearly all organic compounds can be fully oxidized to carbon-dioxide with a strong oxidizing agent (e.g., $Cr_2O_7^{-2}$) under acidic conditions. Silver compounds can also be involved in the COD test to speed up the oxidation of certain organic compounds. Mercury can also be used in the COD test to reduce the interference from oxidation of chloride ions.

5. Concentration of Different Salts as a Limiting Factor in Freshwater Ecosystem

Trophic conditions indicate the biological productivity of the lake. Different trophic classes include Trophic Index (TI), Chlorophyll (Chl), Phosphorus (P) and microorganisms per liter, Secchiidisk Depth (SD), and Trophic Class (Carlson, 1996).

The bottom of the lake contains sufficient amount of organic and dehydrated matter and less amount of electrolyte. In addition, Deep water in most cases does not contain dissolved oxygen. Further, fresh water system receives excess salts from the discharge due to contamination by chemicals, hazardous materials and other foreign particles. Point source pollution refers to contaminants or harmful/ toxic compounds that enter into surface water via a fixed source such as a pipe or ditch. For example discharges pipes from a sewage treatment plant of factories or several other organizations, industries, power plants, underground coal mines, offshore oil wells, etc., whereas Non-Point Source (NPS) pollution resulting from diffuse or vastly scattered sources in contrast to point source pollution. Nonpoint source pollution generally results from surface run-off from agricultural fields (pesticides, chemicals, and fertilizers), overflowing small drains, precipitation, atmospheric deposition, or hydrological modification, rain water sweeping roads ,etc. ,where tracing pollution to a single source becomes extremely difficult.

The toxic substance gets accumulated in the body of organisms at successive trophic levels at a higher concentration than the previous trophic level. For instance, the classic case of DDT pesticides. It is a non-biodegradable chemical. When DDT enters aquatic bodies (like lakes, streams, rivers, etc.), it gets incorporated in the food chain and build up in the body of fishes. When a water body becomes overly enriched with nutrients, leading to excessive growth of growth of algae and plankton.

It is known as Eutrophication which is considered to be a serious environmental matter as it often leads to the deterioration of water quality and the depletion of Dissolved Oxygen (DO) in aquatic bodies. Eutrophic waters can eventually become ‘dead zones’ that are no longer capable of supporting aquatic life (both plants and animals). Over a period of time, anthropogenic activities like use of excessive fertilizers in agricultural field, disposal of nutrient rich waste into water bodies etc. has increased the nutrient content of freshwater bodies ultimately leading to the deterioration of water quality and making it unfit for human consumption. Oil spills leads to the formation of a thick layer of oil on the surface of water. This thick oil layer can stop marine plants from receiving enough light for carrying out the process of photosynthesis as well as it can disturb the free flow of oxygen in the water. This severely affects the floral and faunal biodiversity.

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6. The pH Value of Water as a Limiting Factor for Freshwater Ecosystem

The pH value of pure water is 7, i.e., pure water is neutral. The **pH value** is defined as the effective concentration of H^+ ions present in water. It is determined by the equation:-

$$pH = -\log[H^+] = \log\left[\frac{1}{H^+}\right].$$

Water is considered to be acidic if pH value is less than 7, however it is said to be alkaline if pH value is greater than 7. The range of pH value varies from 0 to 14. Permissible pH value for public supplies may range between 6.6 and 8.4.

The alkalinity is caused by the presence of bicarbonate of calcium and magnesium or by the carbonates of hydroxides of sodium, potassium, calcium and magnesium. Some, but not all of the compounds that cause alkalinity also cause hardness. The pH value is measured by using pH meters. The pH can also be easily measured by indicators as per the specifications given in the table below:

pH Indicator	pH range of indicator dye	Original colour	Final colour produced
Methyl orange	2.8 – 4.4	Red	Yellow
Methyl red	4.4 – 6.2	Red	Yellow
Phenol red	6.8 – 8.4	Yellow	Red
Phenolphthalein	8.6 – 10.3	Yellow	Red

If the pH of water is too high or too low, the aquatic organisms living within the water bodies will die. The pH can alter the solubility as well as toxicity of chemicals and heavy metals in the water. The majority of aquatic creatures prefer a pH range of 6.5-9.0, though some can live in water with pH levels outside of this range. As pH levels move away from this range (up or down) it can stress animal systems and reduce hatching and survival rates. Figure 1.5 is depicting the variation in pH of water.

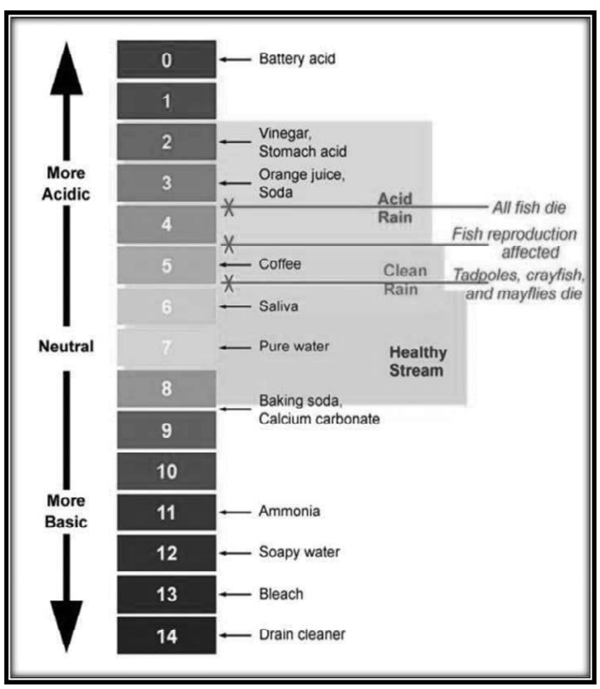

Fig 1.5 *Variation in pH of Water*

7. Salinity of the freshwater as a limiting factor

Anthropogenic activities like agriculture or salt mining or discharge of pollutants in fresh water bodies along with climatic aridification and rising sea levels, are increasing salt concentrations in inland freshwaters as well as coastal habitats, which produces severe negative economic and biological effects. At levels above or below the isosmotic point of organism internal fluids, salinity can disrupt metabolism and water balance. Hence, aquatic organisms have evolved different mechanisms of intra- and extracellular osmoregulation to control osmotic and dehydration stress in the face of salinity changes in the external environment. A change in salinity of the freshwater bodies may adversely affects the growth, survival and reproductive capabilities of the organisms living in it.

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Check Your Progress

1. What do you understand by the term limnology?
2. Define lotic water system.
3. What is latent heat of fusion?
4. How the organisms can be classified on the basis of tolerance to temperature?
5. How the turbidity of water is measured?
6. What is point source pollution?
7. Define eutrophication.
8. What is the permissible pH value for public supplies?

1.4 LAKE- ORIGIN, CLASSIFICATION, DISTRIBUTION AND ECOLOGY

In 1992, Forel defined 'Lake' as a large body of standing water occupying a basin which does not have any connection with sea. Approximately 1% of earth's water is found in lakes, but the renewal time is much more rapid than the ocean. The lake exhibits great variation in size. Lake Superior, the largest body of freshwater flow, has an area of more than 49,600 km^2. Apart from size, lakes also exhibit variation in depth but even the deepest lake will never approaches the depth of ocean. It is important to note that the lake Baikal has a greatest depth contains about 20% of the total volume of freshwater and it is also the deepest known lake with a maximum depth of 1620 m. The characteristics features of lake are as follows:

- Lake consists of one or more basins, partially or completely connected to each other.
- All parts of the lake will have the same water level (except for the effects of wind, ice cover and incoming rainfall).
- The lake usually does not have any connection to the ocean or sea water.
- A significant portion of the sediment suspended in the water will accumulate at the bottom of the lake.
- The average water volume of a lake must exceed a certain limit (e.g. more than 1 hectare).

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1.4.1 Origin of Lakes

Lakes are formed due to:

(1) **Formation of Lakes Due To Glacial Activity**

Glacial lakes are commonly found in North America as well as in other regions formerly traversed by the many glaciers of the last ice age. The grinding weight and pressure of encroaching and retreating ice sheets carved many depressions in the Earth's surface, where melting ice is then collected to form lakes. When ice sheets moved over flat rock surface with weakened areas of fissures, the rock could splinter and loosen to form the basin of 'glacial scour lakes,' such as the Great Lakes in the U.S. and Canada. Further, it has been observed that glacial lakes are often surrounded by other geological evidence of glacial scour. For instance: The Great Lakes in the U.S. and Canada are the best examples of lakes produced by glacial activity. In some areas, as exemplified by the Great Lakes, basins were carved into bedrock by the erosive action of the advancing ice mass. Lake basins are also formed by glacial moraine deposits that dam pre-existing stream valleys. Lakes can form from depressions or dams generated by glacial concentration of rocks and soils; these are referred to as moraine lakes because they form from the rock piles, or moraines, generated by glaciers.

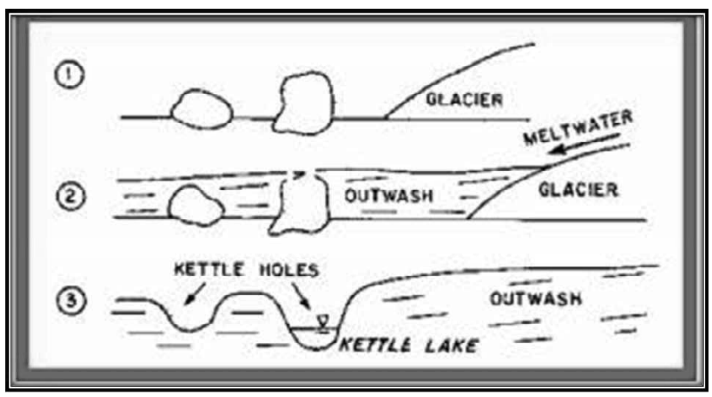

Fig.1.6 *Line Diagram Showing the Formation of Lakes by Glacial Process*

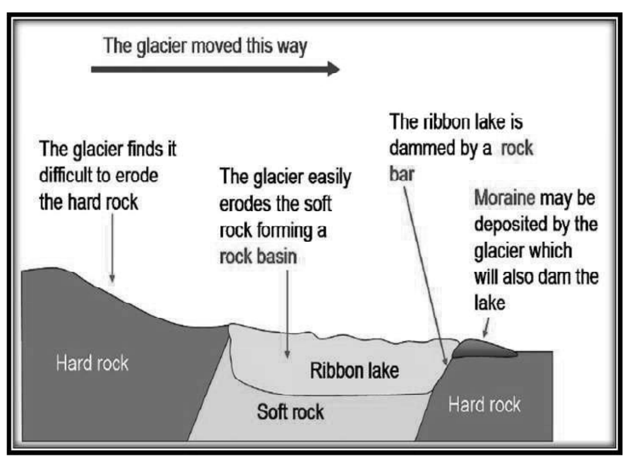

Fig.1.7 *Formation of Ribbon Lake*

Figure 1.7 depicts the formation of Ribbon lake

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(2) **Formation of Lakes due to Volcanic Activity**

Lakes also form in calderas, created by the collapse of volcanic craters. Where extensive limestone deposits underlie a region, groundwater can dissolve great volumes of the limestone, forming caves that often contain underground lakes and eventually, if the roofs collapse, leave deep lake basins. Tectonic activity in the earth's crust forms lake basins in many ways, such as fault-generating rift valleys as those found in E. Africa, that often fill with water. Figure 1.8 depicts the formation of Crater Lake.

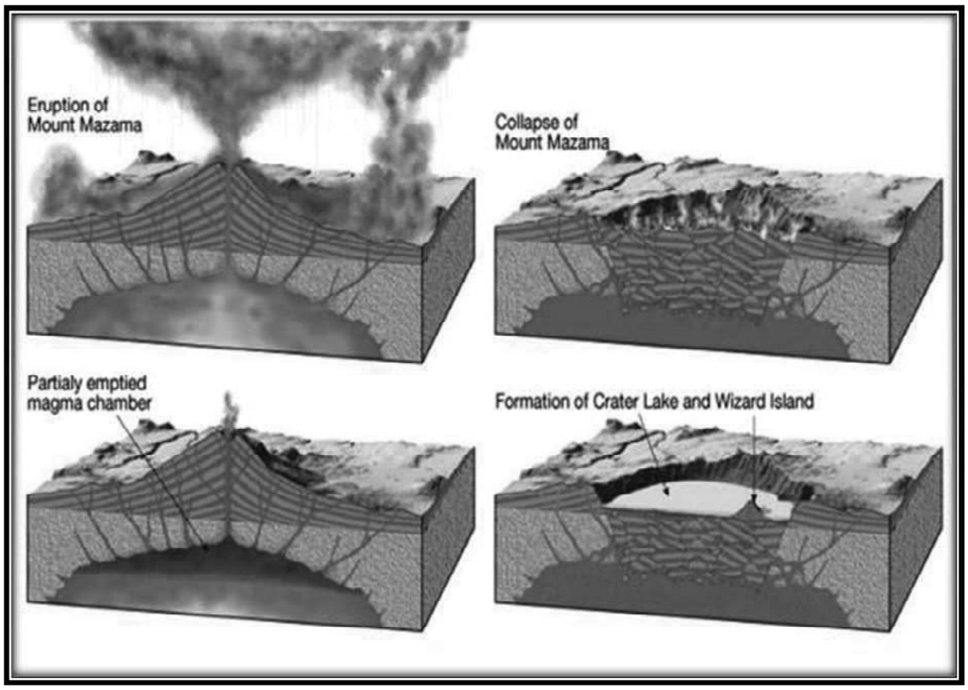

Fig.1.8 *Formation of Crater Lake.*

(3) **Formation of Lakes Due To Tectonic Movement**

Lakes can also be formed by the movement of the tectonic plates that form the Earth's crust. Such lakes are frequently formed at fault lines where plates meet and earthquakes are more common. When neighbouring tectonic plates separate at fault lines, the steep, narrow gap between them leads to the formation of a graben. Some of the largest, deepest, and oldest lakes on earth are graben lakes. These graben lakes host diverse flora as well as fauna. Lake Baikal and the African Rift Valley Lakes, including Lake Tanganyika are few examples of famous graben lakes.

(4) **Formation of Lakes Due To River Erosion**

These lakes are formed by river movements of sediments that gradually create lakes over a period of time. The strong force of water rushing along a riverine flow path can lead to widespread erosion. Over a period of time, eroded areas may become lake basins. When a lake is formed at the foot of a waterfall, it is known as a plunge-pool lake. As riverine erosion occurs, sediments keep on collecting and depositing downstream in the process. Large rivers can deposit sediments in such a way that dams tributary streams and as a consequence of this, new lakes

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are formed. Such lakes are referred to as lateral lakes. At river bends, turbulence as well as deposition of sediment can build up. Sometimes, this sediment causes the river path to divide and may actually dam of a portion of the river bend entirely. The lake formed by the above-mentioned process is known as oxbow lake. A few lakes have also been observed at the mouths of rivers as well as on deltas and are referred to as fluviatile lakes or alluvial fan dam lakes. Such lakes are quite similar to Oxbow Lakes, formed with the aggregation of sediments on a delta closing off otherwise natural water flow. Fluviatile lakes or alluvial fan dam lakes are often young in origin and often disappear with floods or very high water flow. Figure1.9 depicts the formation of an oxbow lake.

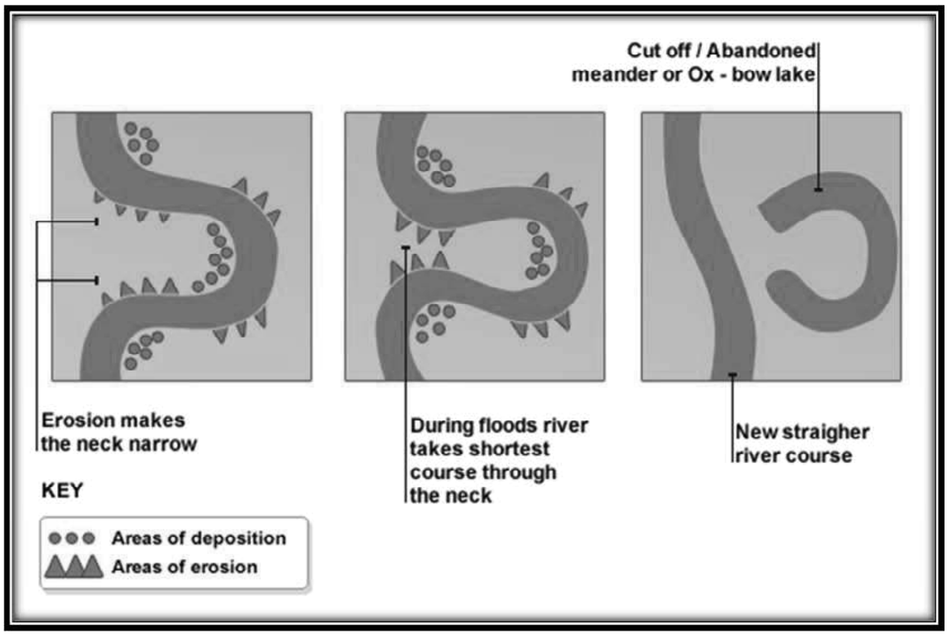

Fig.1.9 *Formation of an Oxbow Lake*

(5) **Man-made Lakes**

Humans often form lakes by building dams across river valleys for flood control, hydroelectric generation, domestic water supply and fisheries, industrial or recreational purposes.

(6) **Other Mechanism of Lake Formation**

Erosive forces can also lead to the formation of lakes. For instance: - The powerful and strong action of waves along ocean shoreline can also lead to lake formation via erosion as well as damming of estuaries and river deltas. The lakes formed by erosive mechanism may be semi-saline brackish water lakes. Even, the strong force of wind is capable of creating lake basins in coastal regions at the boundaries of large lakes by manipulating sand dunes to form temporary depressions where precipitation collects. Wind blowing across geographically flat regions can move or erode soil enough that shallow lakes called deflation basins or playas result. Such shallow lakes are referred as endorheic lakes, i.e., lakes that don't drain into the ocean nonetheless only lose water via the process of evaporation or seepage.

Fig. 1.10 Formation of Shoreline Lakes by Wave Actions and Lake Basins Excavated By Organisms

Figure 1.10 shows the formation of shoreline lakes by wave actions and lake basins excavated by organisms.

Fig. 1.11 Formation of Lake Due to Erosive Action of Wind

Figure1.11 illustrate the formation of lake due to erosive action of wind.

A few lakes are temporary in nature and generally disappear in a relatively short period of geologic time by a combination of processes like erosion of an outlet or climatic changes that bring drier conditions. For instance: In a process known as eutrophication, a lake gradually fills with organic as well as inorganic sediment, becoming a swamp or bog, and eventually a meadow. Human activity has contributed immensely to the increased rates of eutrophication; urban and suburban land construction activities result in increased discharge of soil debris into streams draining into lakes, filling them.

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1.4.2 Classification of Lakes

Lakes are classified on the basis of

(1) Origin

(2) Trophic levels

(3) Mixing of water.

(4) Geography and circulation patterns.

(5) Temperature cycles and stratification

(1) Classification Of Lakes On The Basis Of Origin

- **Tectonic lakes**- They are formed due to tectonic upliftment of a mountain range, leading to the formation of a bowl shaped depression that keeps on accumulating water. For instance- Great Lakes of North America.
- **Lakes formed due to landslides**

  For instance- The Sun Lakes of Washington
- **Salt Lakes**

  Salt lakes are formed when there is no natural outlet or where the water evaporates and water become more salty.

  For instance- Great Salt Lake, the Aral Sea and the Dead Sea.
- **Oxbow Lakes**

  Ox-bow lakes are formed when slow-moving river forms a sinuous horseshoe bend like water body, which is detached from the main river via a narrow neck. Figure 1.12 is depicting the formation of oxbow lake.

Fig. 1.12 *The Formation of Oxbow Lake*

- **Crater Lakes**

  They are formed due to volcanic craters and calderas.

  For instance- Crater Lake in Oregon.

- **Sinkhole Lakes**

  They come into existence as a result of sinkhole activity. For instance: Lake Jackson in Florida, USA,

  Lakes Formed Due To Erosion

- **Kettle Lake**

  Glacial lakes are formed due to melting of glacier, like a kettle lake.

Fig.1.13 *Formation of Glacial Lake*

Figure1.13 is depicting formation of glacial lake

- **Artificial Lake**

  Artificial lakes are generally created by flooding land behind a dam. They are normally referred to as an impoundment or reservoir, for example Hirakund Dam in India.

- **Fjord Lake**: A lake in a glacially eroded valley that has been eroded below sea level.

(2) Classification Of Lakes on The Basis Of Trophic Level

This classification of lakes is based on the productivity of lakes:

Trophic conditions indicate the biological productivity of the lake. Different trophic classes include Trophic Index (TI), Chlorophyll (Chl), Phosphorus (P) and microorganisms per liter, Secchi Disk Depth (SD), and Trophic Class (Carlson, 1996). In this case, the lake is divided into classes as discussed below

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Trophic Index (TI)	Chlorophyll(Chl)	Phosphorous (P)	Secci Disc(SD)	Trophic Class
<30—40	0—2.6	0—12	>8—4	Oligotrophic
40—50	2.6—20	12—24	4—2	Mesotrophic
50—70	20—56	24—96	2—0.5	Eutrophic
70—100+	56—155+	96—384+	0.5—<0.25	Hypereutrophic

a. Oligotrophic Lake

The biological productivity of oligotrophic lake is very low due to its low nutrient content. The water of such lakes is clear and highly transparent.

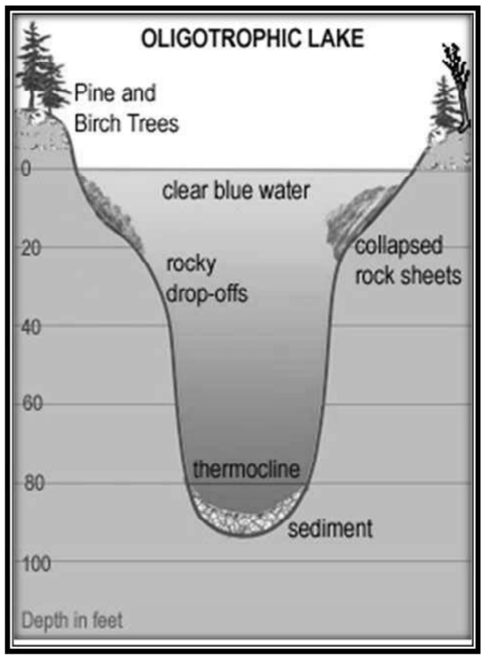

***Fig.1.14** Oligotrophic Lake*

Figure 1.14 illustrates the Oligotrophic Lake.

b. Mesotrophic Lake

The term 'Meso' means medium. Mesotrophic lakes contains moderate amount of nutrients like phosphorus and nitrogen which promotes the growth of planktons.The water of such lakes is clear, with aquatic plants submerged at the bottom and some algae blooms at the end of summer. Figure 1.15 illustrate the Mesotrophic Lake.

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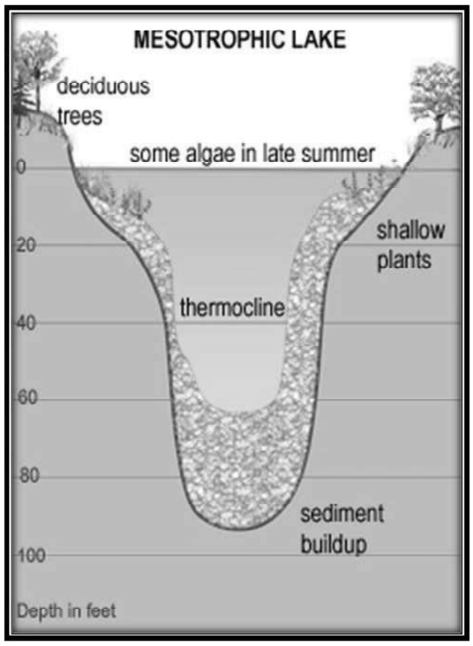

Fig. 1.15 *Mesotrophic Lake*

c. Eutrophic Lakes

The word eutrophic is derived from the Greek word '*eutrophos*' which means rich in nutrients. Eutrophic lakes are those lakes which exhibits very high biological productivity. High nutrient content of eutrophic lakes promotes growth of aquatic organisms. Figure 1.16 illustrate the eutrophic lake.

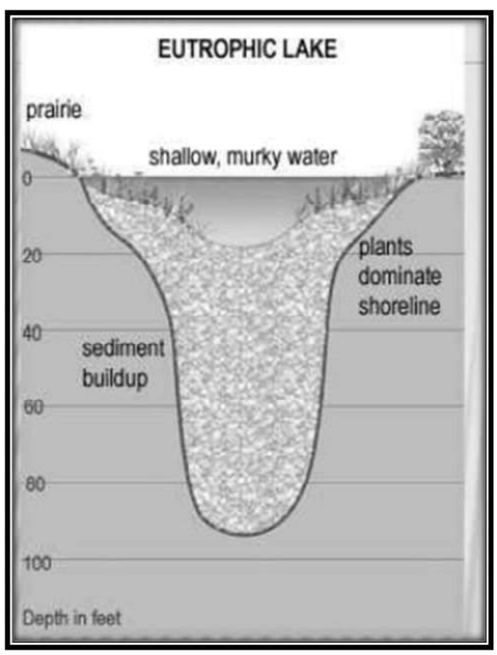

Fig. 1.16 *Eutrophic Lake*

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d. Hypereutrophic Lakes

Hypereutrophic lakes are excessively rich in nutrients leading to algal blooms. Algal blooms leads to reduced dissolved oxygen levels resulting in a low-depth death zone beneath the surface of such a reservoir, which reduces the density of the organism. Figure 1.17 illustrate the Hypereutrophic Lake.

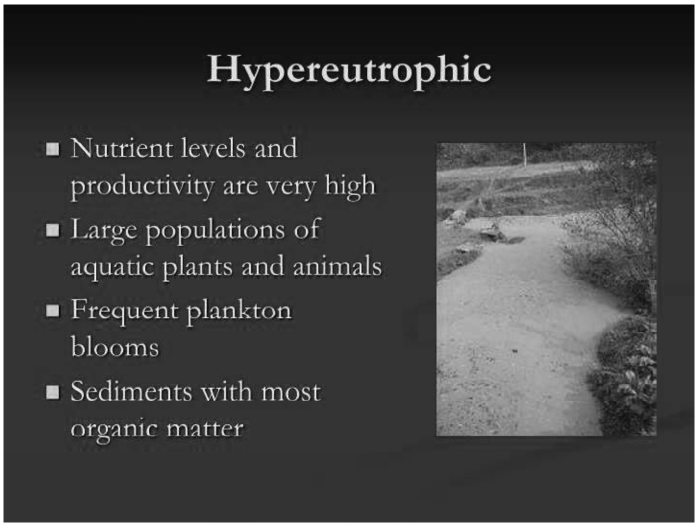

Fig.1.17 *Hypereutrophic Lake*

e. Dystrophic Lakes

Dystrophic lakes are rich in humic substances as well as organic acids, so the water is usually brown or tea-colored. Additionally, the amount of calcium, phosphorus and nitrogen is very low in such lakes. The bottom of the lake contains sufficient amount of organic and dehydrated matter and less amount of electrolyte. In addition, Deep water in most cases does not contain dissolved oxygen.

Table 1.1 *Depicts the Classification Proposed by Naumann (1929)*

Type of Lake	Characteristics of Lake
Oligotrophy	Low nitrogen and phosphorus content hence low biological productivity
Eutrophy	High nitrogen and phosphorous content hence high biological productivity.
Acidotrophy	These lakes have a pH value below 5.5 and hence exhibit low biological productivity.
Alkalitrophy	These lakes are rich in calcium and hence exhibit low biological productivity.
Argillotrophy	Presence of excessive clay particles leading to high turbidity and hence low productivity.
Siderotrophy	Presence of iron in excessive amount and exhibits low biological productivity.
Dystrophy	Presence of excessive humic acid, low nutrient content and low biological productivity.

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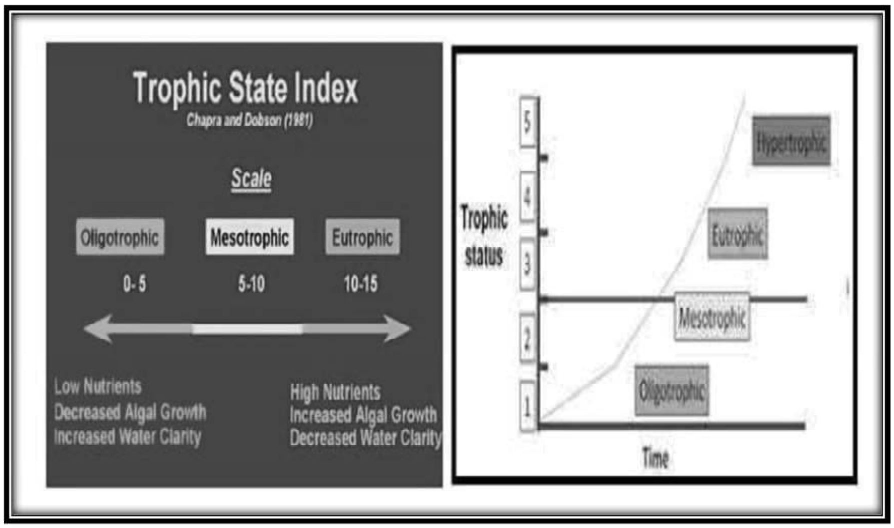

Fig. 1.18 Trophic Status of Lakes

Figure 1.18 is depicting the trophic status of lakes.

(3) Classification of Lakes on the Basis of Mixing of Water

Mixing in water bodies is a function of temperature as well as wind. Three major types of lakes belong to this category:-

a. **Amixis Lakes**- No circulation is observed in such lakes. They are characterized by a lack of mixing. Such lakes usually remain covered with ice covered throughout the year. These lakes are under the polar ice caps (at the North and South Poles of our globe) or high mountain lakes where the temperature is mostly below freezing.

b. **Holomixis Lakes**: These lakes exhibit complete mixing. This is typical situation where the winds mix the "whole" lake water once or more annually.

c. **Meromixis Lakes**: These lakes exhibit partial or incomplete mixing. Some of the lakes have one or more periods of annual mixing. The force of the wind mixes the water of the lake. Figure 1.19 is depicting the stratification in lakes.

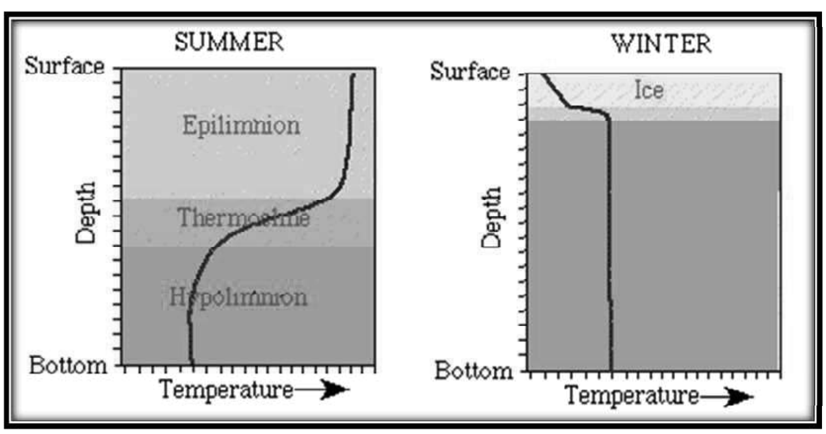

Fig. 1.19 Stratification in Lakes

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(4) Classification of Lakes on the Basis of Geography and Circulation Patterns are as Follows

a. **Polar Lakes:** The surface temperature of polar lakes never falls below 4 degree centigrade.

b. **Lakes in Temperate Regions:** The surface temperature of the lakes found in temperate region varies above and below 4 degree centigrade.

(5) Classification of lakes based on temperature cycles and stratification:

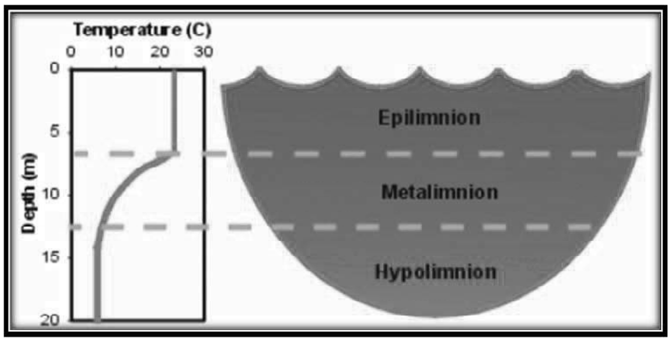

Fig. 1.20 *Thermal Stratification in Lakes*

Figure 1.20 shows the thermal stratification in lakes.

a. **Amictic:** Amictic lakes are permanently frozen below 4 degree centigrade. There is no circulation at all.

b. **Cold Monomictic:** The water at any depth never rises above 4 degree centigrade. Circulation occurs independently in summer and the temperature stays below 4 degree centigrade.

c. **Dimictic:** A dimictic lake is a body of freshwater whose difference in temperature between surface and bottom layers becomes negligible twice per year, allowing all strata of the lake's water to circulate vertically. All dimictic lakes are also considered as holomictic. Figure 1.21 illustrate the annual cycle of a dimictic lake.

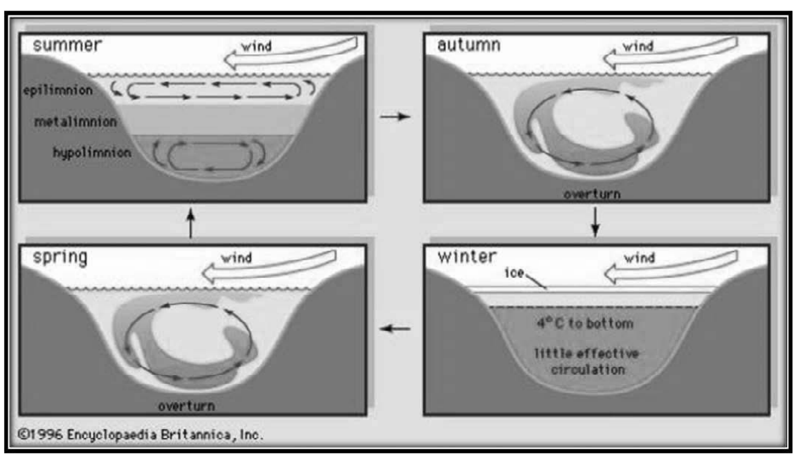

Fig. 1.21 *Annual Cycle of A Dimictic Lake*

Source of figure- Encylopedia Britannica, Inc.

d. Warm Monomictic: The water temperature at any level is never below 4^0C. Circulation occurs independently in winter or directly above 40^0C in summer.

e. Oligomictic: Oligomictic lakes are located in very hot region. Water temperature is always above 4^0C and permanent stratification is normal. As a result of the flow of air, this stratification is soon broken. Such lakes are found in humid tropical regions.

f. Polymictic: Mixtures occur continuously but only at low temperatures (just above 4^0C). There is no thermal stratification.

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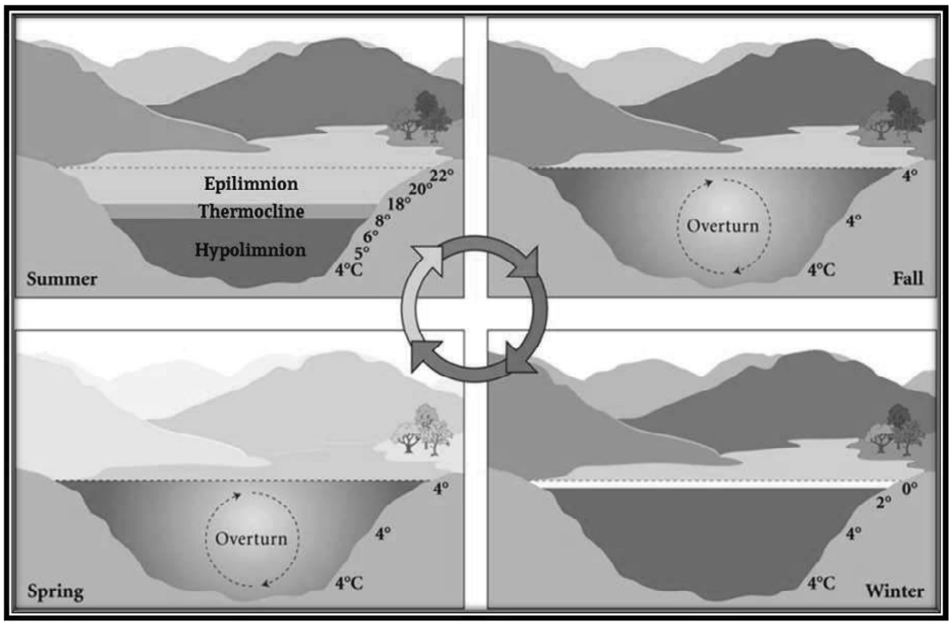

Fig. 1.22 *Thermal Stratification in Lake*

Figure 1.22 illustrates the thermal stratification in lake.

1.4.3 Distribution of Lakes

Lakes are not evenly distributed on the earth's surface; most are located in high latitudes and mountainous regions. More than 60 percent of the world's lakes are in Canada due to deranged drainage system that dominates the country. The license plates of the Canadian province of Manitoba used to claim 100,000 lakes as one-upmanship on Minnesota, whose license plates boast of its 10,000 lakes. Although, most lakes on Earth are fresh water lakes, and are majorly present in Northern Hemisphere at higher latitudes yet various lakes, especially in arid regions, become quite salty as the high rate of evaporation, concentrates inflowing salts. The Caspian Sea, Dead Sea, and Great Salt Lake are among the greatest of the world's salt lakes. The Great Lakes of the United States and Canada is the world's largest system of freshwater lakes. Lake Superior alone is the world's largest freshwater lake with an area of 31,820 square miles (82,414 sq. km), although there is a larger volume of freshwater in Lake Baykal. The Caspian Sea is the largest lake in the world, with an area of144,000 square miles (372,960 sq. km). Lake Titicaca in the Andes Mts. of South America is the world's highest large lake at 12,500 ft.

(3,800 m) above sea level; the Dead Sea is the lowest at c.1, 400 ft. (425 m) below sea level. Majority of the lakes have at least one natural outflow in the form of a river or stream, which keep a lake's average level by allowing the drainage of excess water. Lakes lose water only by evaporation or underground seepage or both. Apart from the natural lake, artificial lakes are constructed for diverse purpose like agricultural use, aesthetic, recreation, industrial use, hydro-electric power generation or domestic water supply. Worldwide, the ponds are greater in number as compared to lakes.

A few important lakes of India Kolleru Lake, Sambhar Lake, Pushkar Lake Lonar Lake, Pulicat Lake, Loktak Lake, Sasthamkotta Lake, Vembana Lake, Chilka Lake, Dal Lake, Nal Sarover Lake, etc.

Table below depicts the list of the largest lakes in India according to the area covered by them

Table 1.2

List of largest Lakes in India (Area covered in Decreasing order)	**State**
Vembanad Lake	Kerala
Chilika Lake	Odisha
Shivaji Sagar Lake	Maharashtra
Indira Sagar lake	Madhya Pradesh
Pangong Lake	Ladakh
Pulicat Lake	Andhra Pradesh
Sardar Sarovar Lake	Gujarat, Rajasthan
Nagarjuna Sagar Lake	Telangana
Loktak Lake	Manipur
Wular lake	Jammu and Kashmir

1.4.4 Ecology of Lakes

The lakes are divided into four different zones: -

(1) Littoral Zone

The **Littoral Zone** is known as the shore area of the lake. The littoral zone consists of the area from the dry land sloping to the open water**.** It allows easy penetration of light. Littoral zone can be very narrow or wide. Oligotrophic lakes have very narrow littoral zones whereas eutrophic lakes have wide littoral zones. The littoral zone obtains a lot of nutrients from runoff water as well as from non-point source pollution favoring the growth of large number of algae and other rooted aquatic plant species**.** A few other familiar inhabitants of the littoral zone are crawfish, snails, insects, cattails, reeds, zooplankton and small fish. The littoral zone adjoins the shore and extends down to a point known as the light compensation level or the depth at which the rate of photosynthesis equals the rate of respiration.

The littoral zone of Lakes exhibits rich biodiversity having a variety of rooted /benthic plants as well as numerous phytoplankton. Rooted plants are generally seen in those areas where light penetrates efficiently to a depth. Emergent plants usually grow well in the riparian areas of water bodies. The rooted parts of these plants are

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attached to the soil near the shore whereas the chlorophyll-bearing portion of the plants are located on the surface of the water. For example *Typhala, Scirpus, Sagitaria* and Pickerel weeds. Deeper than the shore, there are floating leafy plants like water lilies, *Nymphaea, Potamageton*. Rooted weeds are present deep inside the littoral region of the lake, however they are completely submerged. The major phytoplankton of the littoral zone are holophytic blue green algae (*Microcystis, Oscillatoria*) flagellates diatoms and green algae (*Cosmarium, Staurastrum*).

The faunal communities of this region includes: snails, insects, oysters, isopods, nymphs, etc., habituating either the bottom of the mud or present above the mud. Other animals reside in plants that grow on the bottom or in any other object that grows from the top or from the bottom. This includes: *Dysticus, Stentor, Vorticella, Laccotrohes*, Glossophonia, Damsel flies nymphs, Dragonfly, Rotifers (For instance: *Monostylla, Filinia, Asplanchna, Brachionus, Lecane and Keratella Lymnaea, Bellamya,* Bryozoa*, Hydra,* etc.) Further, the larvae of Chironomus are seen in rooted plants. Planarians can be found under the leaves of floating plants.

Zooplankton in the littoral region are water flea such as *Daphnia, Moina*, and Rotifers such as *Brachionus, Keratella* and *Ostracods.*

The nektons found are *Euglena, Coroxa, Dysticus, Paramecium, Gyrinus, Chaoborus, Ranatra,* Culex larva, *Gerris*. Fish species like Bass, Pike, Gar, Sunfish and Top minnows are also seen in the littoral zone.

Periphyton of the littoral zone exhibits a zonation paralleling that of the rooted plants, but several species occur almost through the littoral zone. Among the periphyton forms, pond snails, damselfly nymphs and climbing dragonfly nymphs, rotifers, flatworms, bryozoa, hydra, and midge larvae rest on, or are attached to stems and leaves of the plants.

(2) Limnetic Zone

The Limnetic Zone is known as the open water area of the lake. Limnetic zone is much larger in oligotrophic lakes as compared to eutrophic or older bodies of water. The upper layer of the limnetic zone near the surface of the water is known as euphotic zone or epilimnion (warm water region). Epilimnion receives ample sunlight. Euphotic zone or epilimnion ends where the sunlight fails to penetrate the water. Algae and other aquatic plants thrive well in the euphotic zone along with the littoral zone. This zone is dominated by planktons. This zone also gets rich oxygen supply due to contact with the air.

The limnetic zone comprises all the waters outside the littoral zone and down to the light compensation level. The limnetic zone gets its oxygen supply from the photosynthetic activity of phytoplankton as well as from the atmosphere directly over the lake's surface. The community of the limnetic zone is mostly composed only of plankton, nekton, and sometimes neuston (organisms resting or swimming on the surface). Phytoplankton producers consist of diatoms, green algae, blue- green algae, and algae- like green flagellates, chiefly the dinoflagellates. Many microscopic creatures (like *Volvox, Euglena, Phacus*), fish also occupy limnetic zone. Zooplanktons comprises of Tardigrades, such as *Macrobiotus*, Rotifer, such as *Rotaria, Philodina*, Copepods, and snails. Frogs also live in the limnetic zone. The limnetic nekton consists almost entirely of fish.

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(3) Profundal Zone

Profundal zone or hypolimnion (cold water region) is present below the euphotic zone. The sunlight does not penetrate in this zone. Heterotrophs are predominantly present in this zone. The size of this zone depends on the age and water clarity of the lake. The oxygen supply is not very rich here.

The bottom of a lake, which is beyond the depth of effective light penetration is referred to as the pro-fundal zone. Profundal zone is mostly inhabited by blood worms, oysters, small calms, phantom larvae, annelids, fungi as well as some bacteria most of them are anaerobic in nature. These animals can survive easily in low light as well as low levels of oxygen. Autotrophic organisms fail to thrive in this area due to lack of sunlight. Their major source of energy is dead and decaying organic matter coming from the limnetic zone. All the organisms found in the profundal region are parasitic, carnivores or detritivores in nature. Large fish generally resides in the dark waters of the hypolimnion layer.

(4) Benthic Zone

Benthic zone is the bottom of the lake. It consists of organic sediments and soil. The benthic zone is also referred to as the lake's digestive system. Decomposers are predominantly present in this zone. This is the zone where bacteria decompose organic matter obtained from dead algae, aquatic plants as well as animals and their waste. The rate of decomposition depends upon the organic matter in the lake as well as the type of bacteria carrying out the process of decomposition. Decomposition can take place either aerobically (in the presence of oxygen) or anaerobically (without oxygen). The size of benthic zone increases with the age of the lake.

Rocks can be seen at the bottom of the new lake. Further, dead and decaying organic matter keeps on accumulating in the benthic zone forming muddy or sandy bottoms that make benthos habitable. Most commonly benthic communities includes larvae such as Midge larvae, pit-dwelling May-fly, oysters, snails as well as tube worms.

The primary productivity through photosynthesis of littoral and limnetic zone is more due to greater penetration of light than the profundal zone. Figure 1.23 shows the overview of the Lake Zonation and ecology**.**

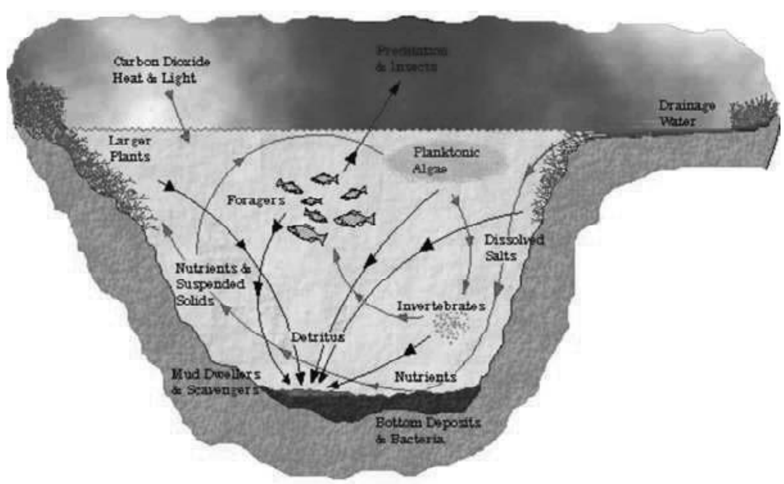

Fig.1.23 *Overview of the Lake Zonation*

1.5 STREAMS- CLASSIFICATION, FORM, ZONATION AND ECOLOGY

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Streams are zones where a quick flow of shallow water creates a shearing stress on the stream bed, leading to a rocky or gravel substratum covered by fully oxygenated water. A stream can be defined as a body of water with a current, and is smaller than a river. When merged, they can form a bigger body of water either flowing or no flowing water ecosystem (like lakes, river, etc.). The size of the stream may vary from tiny rivulet to rivers. Streams are abundantly present in areas of abundant rain fall. Streams can be temporary or permanent. Streams are closely associated to their watersheds. The productivity of streams is regularly dependent on terrestrial bases, grasses as well as other debris.

Physical Conditions of Streams

The annual change in stream temperature varies from 10 to 20°C.

- Temperature of most streams is lowest in the upland; however, it becomes gradually warmer in the lower reaches.
- The velocity of stream water fluctuates with the landforms. For instance, in plain regions, streams are often slow and sluggish through their entire length whereas in hilly areas, velocity of water rises sharply.
- The temperature of the stream fluctuates with air temperature and the factors responsible for this are; water depth, velocity of current, bottom material, temperature of water entering, exposure to direct sunlight as well as degree of shading.
- Turbidity happens in running water series, however in streams with rock beds the turbidity is minimal.
- With age, streams increases in length, width and depth.

Chemical Conditions of Streams

- The Dissolved Oxygen (DO) is very high in uncontaminated stream at all levels.
- The polluted streams exhibit low dissolved oxygen due to accumulation of organic wastes.
- The level of dissolved oxygen is controlled by two factors namely the slope of channel as well as the mode of flow.
- Current in streams tends to keep the pH in uniform over considerable distances.
- The dissolved solids of streams are often affected by their irregular discharges.
- Most streams have highest discharge during winter rains, when particulate matters, nutrients like iron, sulphate, phosphate or nitrate are transported to different parts by the flow of the streams.
- Streams fed by springs have more constant nutrients.

1.5.1 Classification of Streams

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There are three main types of streams:

(1) Ephemeral Streams- A stream that has flowing water only during or for a short duration after precipitation events in a typical year are ephemeral streams. They regularly exist for short periods of time, especially during a rainy period.

(2) Intermittent Streams- A stream that has flowing water during certain times of the year, when groundwater provides water for stream flow. During dry periods, intermittent streams may not have flowing water.

(3) Perennial Streams- A stream that has flowing water year-round during a typical year. The water table is located above the streambed for most of the year. Groundwater is the primary source of water for stream flow. Runoff from precipitation is a supplemental source of water for stream flow.

Streams can also be classified based on their size:

(1) First Order Stream- These streams are not connected to any tributaries (A tributary or affluent is a stream or river that flows into a larger stream or main stem river or a lake.)

(2) Second Order Stream- These streams are connected to one other stream/ tributary

(3) Third Order Stream- These streams are formed by joining together of two second order streams.

1.5.2 Zonation of Streams

Streams exhibits longitudinal zonation or profile instead of horizontal as seen in lakes and ponds discussed in the previous sections. In 1963, Lilies and Botosaneanu have recognized two major subdivisions of a stream/river course:

(1) **Rithron**- The steep and torrential upper course known as rithron. 'Rithron' zone tend to exhibit an alternation between two zones:

   (a) **Rapid Zone-** Steep, narrow and shallow riffles or rapids- Riffles exhibits very high turbulent flow, coarse bottoms of boulders, rocks or pebbles as well as limited attached vegetation.

   (b) **Pool Zone-** Flatter, wider and deeper reaches are termed as pools. Pools exhibits lower flow, bottoms of finer material as well as some rooted vegetation. Pools show turbulent flow and comparatively low temperatures.

(2) **Potamon**- The flat, slow-flowing lower course is known as potamon. Zonation within the potamon is both longitudinal as well as lateral:

   (a) Longitudinally, there is a repetition of different habitats associated with the meanders of the channel.

   (b) Laterally, there is the distinction between the main channel and its floodplain.

The potamon zone is much more complex than the rhithron zone. There is usually a definite series of river channels flanked by a floodplain. Potamon zone consists of both running (lotic) as well as still (lentic) waters. The plain itself holds numerous types of water body, few of them retain water during the inter-flood period. Due to slit, such structures show a succession from open lagoon, through vegetation-lined pools and heavily vegetated swamps to dry land.

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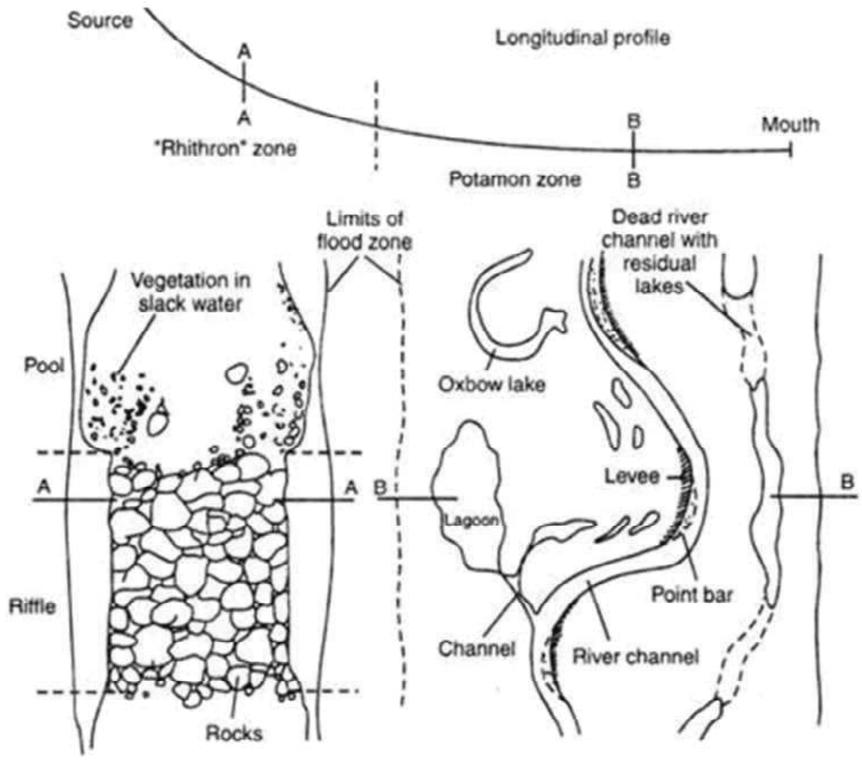

Fig. 1.24 Rithron and Potamon Zone of Streams/Rivers

Figure 1.24 depicts the 'Rithron' and 'Potamon' zone of strems/rivers.

1.5.3 Ecology of Streams

The abiotic factors or environmental factors affecting the streams are as follows:

(1) **Precipitation-** As seen in the above section, the amount of precipitation (rainfall, drizzling, sleet, snow etc.) determines the type of stream formed in the area.

(2) **Current-** Current determine the substrate present at the bottom of the stream.

(3) **Landscape-** The velocity of stream water fluctuates with the landforms. For instance, in plain regions, streams are often slow and sluggish through their entire length whereas in hilly areas, velocity of water rises sharply.

(4) **Temperature-** The temperature of the stream fluctuates with air temperature and the factors responsible for this are water depth, velocity of current, bottom material, temperature of water entering, exposure to direct sunlight as well as degree of shading. Temperature affects the growth, development as well as reproduction of the organism living in the stream.

All the above-mentioned factors affect the biotic communities present in different zones of streams. Biotic communities of the rhithron zone comprises of **plankton,**

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periphyton, 'aufwuchs', nekton as well as benthos. They are described as follows:

(1) Phytoplankton are the major primary producers in the rhithron zone. Phytoplankton are small microscopic, unicellular and photosynthetic organisms which freely float in water bodies. Phytoplankton composed of both eukaryotic as well as prokaryotic species which colonizes upper euphotic part of the water column. In the rhithron zone of comparatively undisturbed stream, the major primary producers are the filamentous green algae like Ulothrix and Cladophora and diatoms like Nizschia and Gomphonema. Ulothrix belongs to the class **Chlorophyceae**. They are usually green due to the presence of pigments like chlorophyll a, chlorophyll b and beta-carotene. Pigments are present in plastids or chromatophores. Starch is the main photosynthetic food product. In chromatophores pyrenoids are present. Both flagella are equal in length, i.e., they are isokonatae. Cell wall is made up of cellulose. **Diatom** are members of the class Bacillariophyceae (division Chromophyta), with approximately 16,000 species found in sediments or attached to solid substances in aquatic bodies. The markings of cell wall, structure and position of raphae and nodules are the distinguishing features for identification of species. The diatom cell is well known as frustules and typical feature is possession of silica cell wall. This structure is extremely ornamental, which is species specific and frequently used as means of identification. Diatoms are among the most significant and productive microscopic sea organisms and serve directly or indirectly as food for many animals.

(2) **Aufwuchs:** Those organisms that attach firmly to a substrate (submerged rocks, plants, debris) but do not penetrate it (in contrast to plants rooted in the bottom or certain parasites) are collectively called known as **'Aufwuchs'.**

(3) **Zooplankton:** The zooplankton of the 'Rhithron zone' majorly comprises of ciliate protozoans (for example *Vorticella*) Rotifers (for example *Asplancha, Brachionus, Keratella, Philodina*), and crustaceans (for example *Daphnia, Bosmina, Cyclops, Diaptomus, Gammarus pulex*). Algae, small crustaceans, rotifers, and protozoans are the examples of aufwuchs.

(4) **Commonly Found Insects in Streams**

(a) Mayflies belongs to the insect order Ephemeroptera, for example *Rhithrogena, Ameletus, Caenis, Baetis rhodani, Ephemerella, Ecdyonurus, Epeorus*, etc.

(b) Stoneflies belonging to the order Plecoptera, for example *Protonemura, Leuctra, Diura, Brachypterd Nemoura, Perlodes, Arcynopteryx, Perla, Isoperla*.

(c) Caddisflies belonging to the order Trichoptera (*Rhyacophila, Philopotamus, Hydropsyche, Drusus, Agraylea, Limnephilus*.

(d) Insects belonging to the order Diptera, for example *Chironomus riparius, Simulium*.

(e) Dragonflies belonging to the order Odonata, for example *Libellula*.

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(5) Benthic Organism in Streams: Benthic organisms are present on the sea bed that are sessile, burrowing, creeping, etc. Some worms are commonly present in streams, for example flatworm (*Dugesia)*, roundworm (*Dolichodorus)*, annelid worm (*Tubifex*), leeches (*Glossiphonia, Haemopis, Erpobdella*), molluscus (*Dreissena, Bithynia*,) and crustacea (*Gammarus*) may also occur among the benthic forms.

(6) Nektons Present in Streams: The term nekton is used for actively swimming organisms. Nekton community residing in streams comprises of water bugs belonging to the insect order Hemiptera,(*Micronecta, Gerris, Notonecta, Corixa*), beetles belonging to the order Coleoptera,(*Dytiscus*) and fish.

Fish species residing in rhithron zones belongs to two categories:

(a) Small size fish species which live among rocks of the bottom and are are adapted to grip or cling to the substrate. (*Pseudecheneis, Astroblephus, Chiloglanis, Glyptothorax*, etc.).

(b) These fish species are adapted to swim fast as to resist the water current or even swim against it. (*Salmo, Barbus, Schizothorax, Barilius*, *Tor*, etc.).

The biotic communities of potamon zone are as follows:

(1) Plankton: The presence of plankton is associated with the flow conditions. During floods, rare planktonic organisms may be present however during dry seasons algal blooms may develop within the lentic waters of the plain as well as in the main channel. In short rivers, these are usually confined to backwaters whereas in extended rivers the time taken for specific masses of water to travel downstream is enough to let the development of plankton.

(a) Algae and Diatoms: Algae and Diatoms are the most common phytoplankton present in potamon zone of streams. The type of algal species growing in potamon zone depends upon its tolerance to pollution. For instance, algal species like *Euglena viridis, Scenedesmus quadricauda, Microcystis, Oscillatoria limosa, Ankistrodesmus falcatus, Phacus caudatus, Navicula viridula, Stigeoclonium tenue, Chlorella vulgaris, Synedra ulna and P. viridis* are regularly limited to the sites of urban and industrial discharge. However, algal species like *Anabaena circularis*, *Gomphonema parvulum, Phormidium uncinatum, Pediastrum duplex, Cymbella turgida, Oscillatoria princeps, Scenedesmus dimorphus, Closterium acerosum, Synedra acus, Navicula cuspidate* are predominantly present in clean or moderately polluted zones.

Further, algal species like *Oscillatoria subbrevis, Melosira ambiguans, Pediastrum simplex, Phormidium calcicole, Merismopedia glauca, Gomphonmea species* are present in highly clean water.

(b) Zooplankton: Zooplankton members of the potamon zone comprises of members like copepoda, protozoa, rotifera Cladocera. Further, species like *B. quadridentate, B. forficula, B .calyciflorus, Filinia* *longiseta, K.cochlearis, Brachionus angularis, Keratella tropica* are present in both clean as well as moderately polluted waters. However, species like *Rotatoria rotatoria Platiyas, polyacanthus Brachionus rubens* are representative of polluted parts of the potamon zone.

(2) **Nekton:** The term nekton is used for actively swimming organisms. A few insects like beetles and fish are pre-dominantly present in the potamon zone.

Potaman zone serves as a habitat to two major group of fish communities. Firstly, there are fish species which are highly adapted to resisting low dissolved oxygen concentration. For example *Notopterus, Erythrinus, Clarias, Channa*, etc. Other group of fish species which habitats the main channel are *Labeo species, Catla catla, Mystus (Aorichthys) species* and *Cirrhinus mrigala*.

(3) **Benthos:** Benthic organisms are sessile, burrowing, creeping animals that are present on the sea bed. Condition of the potamon zone like heavy siltation, seasonal desiccation as well as unstable mud bottoms are not favourable for bottom living organisms. Some of the benthic forms present in potamon zone are: molluscs (like *Corbiula, Lymnaea* and *Bithynia*) as well as certain worms and leeches.

(4) **Macrophytes:** The presence of macrophytes is a distinguishing feature of the potamon zone. The free-floating macrophytes like *Eichhornia crassipes* (water cabbage), *Salvinia* (water fern) and *Pistia* (water lettuce) are most commonly observed macrophytes in potamon zone. Rooted macrophytes either completely submerged or having a part of their vegetative or sexually reproductive parts exposed like Myriophyllum (milfoil),

Potamogeton (pond weed), *Ceratophyllum* (coontail) and *Nymphaea* (waterlily) are commonly found in potamon zone.

1.5 SPRINGS

A spring is referred to as a water resource formed when the side of a hill, a valley bottom or other excavation intersects a flowing body of groundwater at or below the local water table, below which the subsurface material is saturated with water. A spring is the consequence of an aquifer being filled to the point that the water overflows onto the land surface. Springs varies in size from intermittent seeps (which flow after heavy rainfall) to huge pools flowing hundreds of millions of gallons on daily basis. However, springs are not restricted to the Earth's surface. Lately, scientists have revealed hot springs at depths of up to 2.5 km in the oceans. The hot water having a temperature of over 300 degrees Celsius, coming from such springs is enriched with minerals as well as sulphur leading to a unique ecosystem, where rare and exotic sea life seems to flourish. The amount of water that flows from springs depends on several factors:

- The size of the spring basin.
- Size of the caverns within the rocks.

- The water pressure in the aquifer.
- Amount of rainfall.
- Anthropogenic activities can also influence the volume of water that gets discharged from a spring. High groundwater withdrawals in an area due to human activities can cause water levels in the aquifer system to drop which ultimately decreases the flow from the spring. Figure 1.25 depicts the formation of springs.

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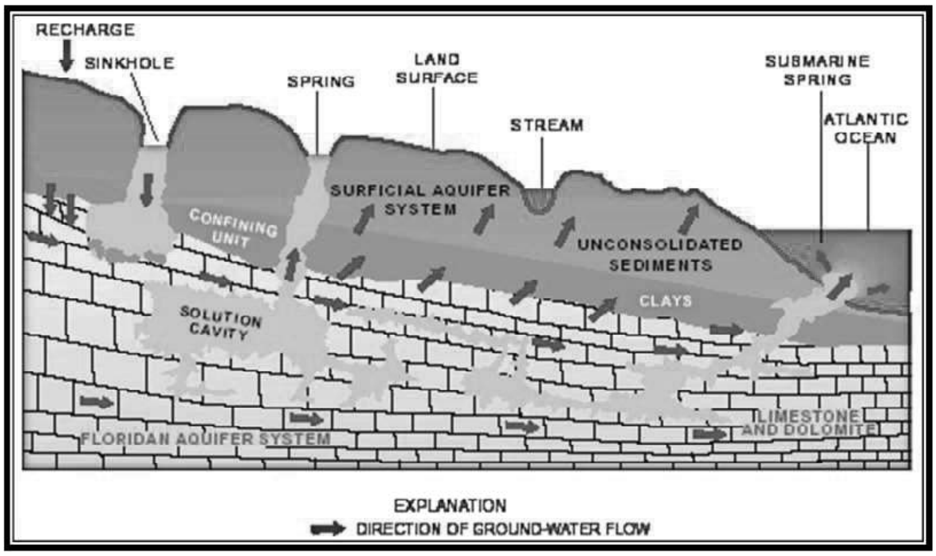

Fig.1.25 *Formation of Springs*

1.5.1 Forms of Springs

- **Depression Springs-** Depression springs occur along a depression. For instance: bottom of alluvial valleys, basins, or valleys made of highly permeable materials.
- **Gravity Springs-** Gravity springs are formed by water soaking into the ground until the water encounters a confining layer that will not let the water seep further down. The water then flows across the top of the confining layer until it reaches the ground surface. Figure 1.26 depicts a depression spring.

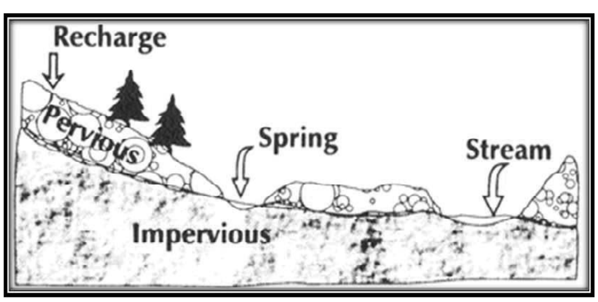

Fig. 1.26 *Depression Spring*

- **Contact Springs-** Contact springs occur along the side of a mountain or hill. They are shaped when the groundwater is underpaid by an impermeable layer of soil or rock referred to as aquifuge or aquiclude.

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- **Fracture Joint or Tubular Springs-** Fracture joint or tubular springs occur when groundwater running along an impermeable layer of rock encounters a fracture or crack or joint in the rock. This is the reason such springs are referred to as fracture joint or tubular springs.
- **Artesian Springs**- Artesian springs characteristically happen at the lowest point in a given area. Such types of springs are formed when the pressure for the groundwater turn out to be greater as compared to pressure from the atmosphere. Figure 1.27 is depicting an artesian spring.

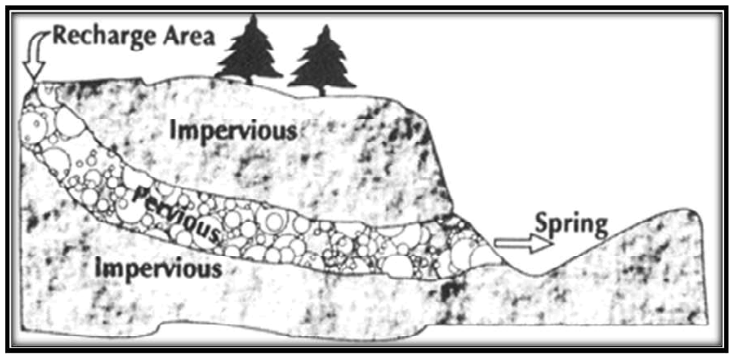

Fig. 1.27 *Artesian Spring*

- **Hot Springs**- As the name suggests, the water temperature of such springs are suggestively higher than the mean air temperature of the adjacent area.
- **Karst Springs** – Karst springs includes the largest discharges of groundwater from a single orifice. These springs are the distal zones where karst ground waters, commonly recharged in sinkhole plains, re-emerge at lower elevations, commonly after flowing through tens or hundreds of kilometres of cave systems
- **Contact Springs**- Contact springs emerge along the interfaces of geologic formations that have greatly differing permeabilities. Most common are springs in sedimentary sequences where sandstone overlies shale.
- **Quaternary Volcanic Springs** - Numerous recent volcanic deposits (less than 1 Ma), specifically those of basaltic composition host a long-range subsurface channels or tubes or ducts that were previously lava tubes. Once the lava cools down, a vacant cavern remains many miles long. These caverns tend to fill with groundwater and at the end of the tubes high volume spring discharge will emerge. The volcanic edifice is the main source region of the basaltic flow and it capture precipitation , that infiltrates and recharges these buried conduits. Figure 1.28 illustrate different types of gravity springs.

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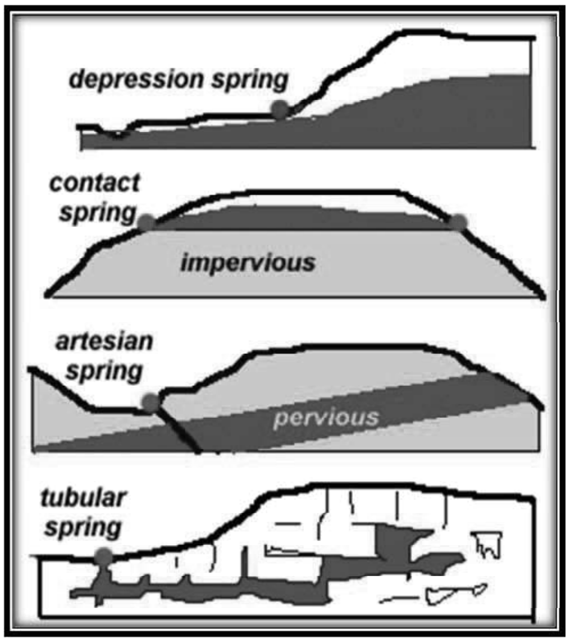

Fig. 1.28 *Different Types of Gravity Springs*

1.5.2 Classification of Springs

The classification of springs is based on the volume of the water they discharge. They are classified as follows:

Magnitude	Flow (ft^3/s, gal/min, pint/min)	Flow (L/s)
0 magnitude	no flow (sites of past/historic flow)	
1st magnitude	> 100 ft^3/s	2800 L/s
2nd magnitude	10 to 100 ft^3/s	280 to 2800 L/s
3rd magnitude	1 to 10 ft^3/s	28 to 280 L/s
4th magnitude	100 US gal/min to 1 ft^3/s (448 US gal/min)	6.3 to 28 L/s
5th magnitude	10 to 100 gal/min	0.63 to 6.3 L/s
6th magnitude	1 to 10 gal/min	63 to 630 mL/s
7th magnitude	2 pint to 1 gal/min	8 to 63 mL/s
8th magnitude	Less than 1 pint/min	8 mL/s

Properties of Spring Water

The properties of the spring water are as follows:

- Water from springs is usually colourless and highly transparent.
- However, a few springs may get their colour by the minerals that are dissolved in the water. For example, water heavy containing iron or tannins will have an orange colour.
- Minerals get dissolved in spring water as it moves via underground rocks.
- This total mineral content in spring water is referred to as total dissolved solids (TDS).
- This mineralized water has a different taste and even carbon dioxide bubbles might be present depending on the nature of the geology through which it passes.

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- Spring water that contains substantial amounts of minerals are sometimes referred to as 'mineral springs'.
- On the contrary, springs lacking in mineral content are referred to as sweet springs.
- Further, springs that comprises of large quantities of dissolved sodium salts (Na salts), generally sodium carbonate, are known as 'soda springs'.
- Mineral springs are supposed to have some healing properties and hence are used in spas for giving water therapies.
- Groundwater helps to keep a relatively long-term average temperature of its aquifer; hence flow from a spring may be cooler than other sources on a summer day, however remain unfrozen during the winter season.

1.5.3 Use of Springs

Springs fulfils a variety of human needs:-

- Drinking purposes
- Household chores
- Agricultural activities like irrigation
- In mills,
- For navigation,
- For electricity generation,
- Recreational activities like fishing, swimming, and floating, etc.
- For rejuvenating therapy (like in spas),
- Water for livestock,
- As fish hatcheries,
- Commercial purpose like to be supplied as bottled mineral water popularly known as bottled spring water.

Check Your Progress

9. Name the largest body of fresh water.
10. What is an ox-bow lake?
11. State about the amictic lakes?
12. Define a stream.
13. What are intermittent streams?

1.6 PONDS

Pond is defined as a small, shallow inland stagnant water body which is smaller than a lake. Ponds can be either natural or artificial. The marsh, aquatic plants and various aquatic animals live mainly in the pond water depending upon the factors like: depth of the water in the pond, penetration level of sunlight, presence of food, presence of dangerous or harmful animals etc.

General Characteristics of Pond

- Ponds are defined as small, shallow standing water bodies (Lentic water bodies).
- The average depth of a pond varies from 8-10 feet.
- Ponds have calm standing water with minimal movement.
- Though, the water remains standing yet definite amount of water movement may be seen like wave action or internal currents.
- Ponds serves as the habitat for several aquatic plants as well as animals.
- Ponds have varying temperature depending upon the season or in other words temperature of ponds fluctuates with season.
- Light can penetrate deep into the pond nearly up to the bottom.

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1.6.1 Classification of Ponds

Ponds are divided into two general classes based on seasonal duration

a. **Permanent Ponds** – Permanent ponds are those which hold some water throughout the year.

b. **Temporary Ponds** – Temporary Ponds are those in which the basin have water in some seasons, however, it gets dry in others. Generally, three types of temporary ponds are observed in temperate regions.

   (1) Spring or Vernal pond: Spring pond has water only in spring season.

   (2) Autumn Ponds or Vernal Autumn Ponds: Autumn ponds dry up in summer while it is full of water in spring as well as autumn season.

   (3) Summer Pond or Aestival: Water is present throughout the year in summer pond, however, during winters ice accumulates at the bottom in such ponds.

Other Classifications of Ponds

In the next section, we will discuss other methods of classifying ponds.

(1) Classification of ponds on the basis of their origin:

(a) **Natural Pond:** Natural ponds are perennial shallow water bodies. When a stream changes its course, it leaves behind an isolated body of standing water (lentic water) leading to the formation of natural pond. In limestone regions, depressions are created due to the solution of the underlying strata. The water gets accumulated in such depression either by floods or rainfall leading to the formation of natural ponds. Occasionally, a natural pond is created by the elimination of a lake whose basin (bottom) is never as deep as a lake.

(b) Artificial Pond: Artificial ponds are results of anthropogenic or human activities like excavation, dam construction. The water level of an artificial pond can be regulated by inflow and drainage.

Most of the fish ponds are semi artificial ponds.

Artificial pond can further be classified on the basis of construction method or construction material used for making pond.

Classification of artificial ponds on the basis of construction method used:

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1. **Dug Out (excavated pond) Pond**: Dug out (excavated pond) pond are constructed by excavating soil from an area to form a hole which gets filled by rain water, surface runoff or groundwater.
2. **Embankment Pond:** Embankment pond are formed by building one or more dikes above ground level to impound water. Such ponds are usually drainable and fed by gravity flow of water or by pumping.
3. **Cut and Fill Pond**: Cut and Fill pond are constructed by a mix of excavation and embankment on sloping ground.

Classification of artificial ponds on the basis of construction material used:

(1) Earthen Ponds: Earthen ponds are the most common ponds made up from soil materials.

(2) Walled Ponds: Walled ponds are surrounded by blocks, bricks or concrete walls. Sometimes wooden planking or corrugated metal is also used in the construction of walled ponds.

)3) Lined Ponds: These are earthen ponds only which are lined with an impervious materials like plastic or rubber sheet.

Ecological Zonation of Ponds

Ponds can be vertically divided into different levels based on the penetration of light, wavelength absorption, surface pressure, temperature, etc.

(1) Littoral Zone

- The littoral zone is known as the shore area of the pond.
- The littoral zone consists of the area from the dry land sloping to the open water.
- It allows easy penetration of light.
- Littoral zone can be very narrow or wide.
- Oligotrophic or young ponds have very narrow littoral zones whereas eutrophic or old ponds have wide littoral zones.
- The littoral zone obtains a lot of nutrients from runoff water as well as from non-point source pollution favoring the growth of large number of algae and other rooted aquatic plant species.
- A few other familiar inhabitants of the littoral zone are crawfish, snails, insects, cattails, reeds, zooplankton and small fish.

(2) Limnetic Zone

- The limnetic zone is known as the open water area of the lake or pond.
- Limnetic zone is much larger in younger ponds or oligotrophic ponds as compared to eutrophic or older bodies of water.

- The upper layer of the limnetic zone near the surface of the water is known as euphotic zone or epilimnion (warm water region).
- Epilimnion receives ample sunlight.
- Euphotic zone or epilimnion ends where the sunlight fails to penetrate the water.
- Algae and other aquatic plants thrive well in the euphotic zone along with the littoral zone.
- This zone is dominated by planktons.
- This zone also gets rich oxygen supply due to contact with the air.

(3) Profundal Zone

- Profundal zone or hypolimnion (cold water region) is present below the euphotic zone.
- The sunlight does not penetrate in this zone.
- Heterotrophs are predominantly present in this zone.
- The size of this zone depends on the age and water clarity of the pond or lake.
- The oxygen supply is not very rich here.

(4) Benthic Zone

- Benthic zone is the bottom of the pond or lake.
- It consists of organic sediments and soil.
- The benthic zone is also referred to as the pond's or lake's digestive system.
- Decomposers are predominantly present in this zone.
- This is the zone where bacteria decompose organic matter obtained from dead algae, aquatic plants as well as animals and their waste.
- The rate of decomposition depends upon the organic matter in the pond as well as the type of bacteria carrying out the process of decomposition.
- Decomposition can take place either aerobically (in the presence of oxygen) or anaerobically (without oxygen).
- The size of benthic zone increases as the pond or lake ages.

The primary productivity through photosynthesis of littoral and limnetic zone is more due to greater penetration of light than the profundal zone.

The major difference between lakes and ponds zonation is that the limnetic and Profundal regions of the lake are much larger than the littoral regions. Figure 1.29 is depicting the ecological zonation in a pond ecosystem.

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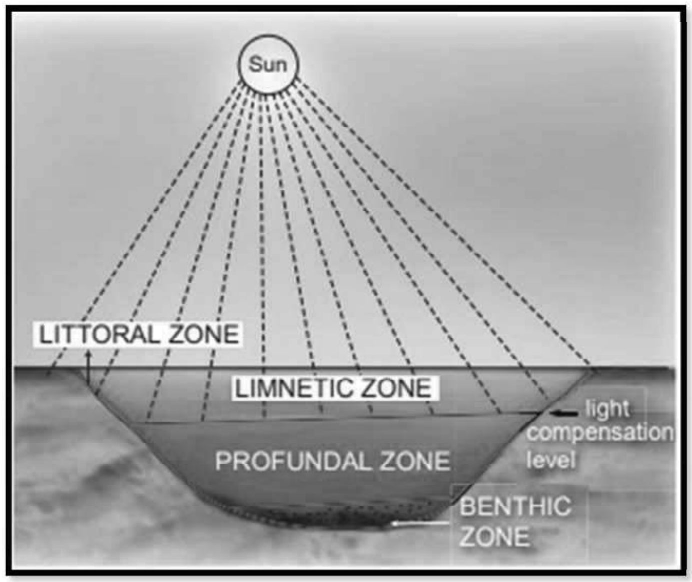

Fig.1.29 Ecological Zonation in a Pond Ecosystem

1.6.2 Pond Ecosystem

The pond ecosystem is a natural, aquatic, freshwater, lentic type of ecosystem. It is a self-sustaining and self-regulatory fresh water ecosystem, which shows a complex interaction between the abiotic and biotic components in it. Figure 1.30 shows structure of Pond ecosystem.

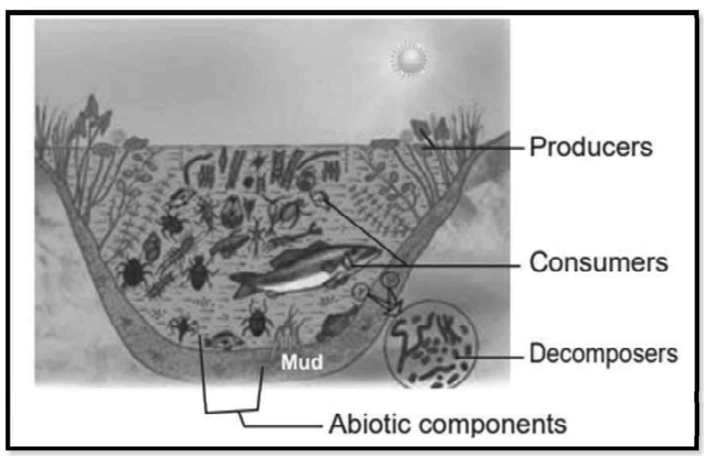

Fig. 1.30 Structure of Pond Ecosystem

Abiotic Components of Pond Ecosystem

Pond ecosystem consists of dissolved inorganic (CO_2, O_2, Ca, N, Phosphate) as well as organic substances like amino acids and humic acid formed from the dead and decaying organic matter. The limiting factors for a pond ecosystem are amount of light received, penetration of light, temperature, pH value of water and other local climatic conditions.

Biotic Components of Pond Ecosystem

Biotic components constitute the producers, consumers and decomposers (microorganisms).

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a. Producers

Major producers of the Pond ecosystem are:

- Phytoplankton like Oscillatoria, Anabaena, Eudorina, Volvox and Diatoms.
- Filamentous algae such as Ulothrix, Spirogyra, Cladophora and Oedogonium.
- Floating plants like Azolla, Salvia, Pistia, Wolffia and Eichhornia.
- Sub-merged plants, such as, Potamogeton and Phragmitis.
- Rooted floating plants like Nymphaea and Nelumbo.
- Macrophytes like Typha and Ipomoea.

b. Consumers

Consumers of the Pond ecosystem are as follows:

- Primary consumers are zooplanktons like Paramecium and Daphnia
- Secondary consumers like water beetles and frogs
- Tertiary consumers like duck, crane, etc.
- Top carnivores like large fish, hawk, man, etc.
- Benthos (bottom living animals) like mollusces and annelids.

c. Decomposers

Decomposers are present in mud water and bottom of the ponds and helps in the recycling of nutrients by carrying out the process of decomposition. For instance: Bacteria and Fungi are decomposers.

The major difference between lakes and ponds zonation is that the limnetic and Profundal regions of the lake are much larger than the littoral regions.

Table 1.3 below depicts the major differences between pond and lake.

Table 1.3

Parameter of Comparison	**Pond**	**Lake**
Size	Usually smaller	Most of the time bigger
Depth	Shallow	Deeper
Photosynthesis activity	More photosynthesis activities	Less activities
Presence of Aquatic life	More plants survival	Lesser plants
Temperature	Usually consistent all year round	Different layers have different temperature

NOTES

Check Your Progress

14. Define ponds.
15. What are hot springs?
16. Why the productivity of littoral and limnetic zone is more in comparison to profundal zone?
17. In which zone of pond, bacteria decompose organic matter ?
18. What are the limiting factors for a pond ecosystem?

1.7 ANSWERS TO 'CHECK YOUR PROGRESS'

1. Limnology is referred to as a division of ecology or environmental science. The term Limnology is derived from Greek word; *Limne* means lake and *logos* means knowledge and is defined as "the study of inland waters" (running and standing waters, fresh and sometimes saline water; natural or man-made water).
2. Lotic aquatic systems contain free flowing waters. Streams as well as rivers are familiar examples of lotic systems. Streams as well as rivers are familiar examples of lotic systems. The primary role of these lotic bodies of water is to carry the surplus rain water back to the sea. Water in a lotic system is derived from diverse sources.
3. Latent heat of fusion is the heat required by a specific quantity of the substance to change its state from a solid to a liquid, at constant pressure.
4. On the basis of tolerance to temperature, organisms can be classified as stenothermal and eurythermal organisms. Eurythermal organisms are those organisms which can withstand a wide range of temperature, whereas stenothermal organisms are those organisms that only survive in a narrow temperature range.
5. Turbidity refers to the measure of relative clarity of a liquid. It is an optical characteristic of water and is a measurement of the amount of light that is scattered by material present in the water, when a light is passed through the water sample. The turbidity of the water is measured by using an instrument known as turbidity rod or by a turbidity meter with optical observations.
6. Point source pollution refers to contaminants or harmful/toxic compounds that enter into surface water via a fixed source such as a pipe or ditch. For instance: Discharges pipes from a sewage treatment plant of factories or several other organizations, industries, power plants, underground coal mines, offshore oil wells, etc.
7. Eutrophication refers to the process in which a water body becomes overly enriched with nutrients, leading to excessive growth of growth of algae and plankton.

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8. The pH value of pure water is 7, i.e., pure water is neutral. **pH value** is defined as the effective concentration of H^+ ions present in water. Permissible pH value for public supplies may range between 6.6 to 8.4.
9. Lake Superior, is the largest body of freshwater flow with an area of more than 49,600 km^2.
10. Ox-bow lakes are the lakes which are formed when slow-moving river forms a sinuous horseshoe bend like water body which is detached from the main river via a narrow neck.
11. Amictic lakes are permanently frozen lakes below 4 degree centigrade. There is no circulation of water at all. They are characterized by a lack of mixing. Such lakes usually remain covered with ice covered throughout the year. These lakes are under the polar ice caps (at the North and South Poles of our globe) or high mountain lakes where the temperature is mostly below freezing.
12. A stream can be defined as a body of water with a current, and is smaller than a river. Streams are zones where a quick flow of shallow water creates a shearing stress on the stream bed, leading to a rocky or gravel substratum covered by fully oxygenated water.
13. Intermittent are the streams that has flowing water only during certain times of the year, when groundwater provides water for stream flow. During dry periods, intermittent streams may not have flowing water.
14. Pond is defined as a small, shallow inland stagnant water body which is smaller than a lake. Ponds can be either natural or artificial. Ponds have varying temperature depending upon the season or in other words temperature of ponds fluctuates with season.
15. Hot springs are the springs in which the water temperature are suggestively higher than the mean air temperature of the adjacent area.
16. The primary productivity through photosynthesis of littoral and limnetic zone is more due to greater penetration of light than the profundal zone.
17. Benthic Zone is the bottom of the pond or lake it is the zone where bacteria decompose organic matter obtained from dead algae, aquatic plants as well as animals and their waste.
18. The limiting factors for a pond ecosystem are amount of light received, penetration of light, temperature, pH value of water and other local climatic conditions.

1.8 SUMMARY

- Limnology is referred to as a division of ecology or environmental science.
- Physical limnology deals with the physical properties of freshwater bodies like lakes and rivers. Studying physical limnology includes changes in light levels, water temperatures as well as water currents

- Fresh water is any naturally occurring water containing low concentrations of dissolved salts and other total dissolved solids.
- Lentic water aquatic system contains standing or stagnant water.
- Wetlands are referred to as the ecotones or transitional zones between permanently aquatic and dry terrestrial ecosystems
- Phytoplankton are small microscopic, unicellular and photosynthetic organisms which freely float in water bodies.
- Benthic organisms are present on the sea bed that are sessile, burrowing, creeping, etc.
- Dissolved Oxygen (DO) is a measure of how much oxygen is dissolved in the water - the amount of oxygen available to living aquatic organisms.
- Eutrophication refers to the process in which a water body becomes overly enriched with nutrients, leading to excessive growth of growth of algae and plankton.
- Biochemical Oxygen Demand (BOD) is referred as the amount of oxygen needed or demanded by aerobic microorganisms to break down the organic matter present in a certain sample of water at a specific temperature over a given period of time.
- The Chemical Oxygen Demand (COD) represents the amount of oxygen necessary for the aerobic biological oxidation (breakdown) of the organic substances in a given water body or sample to carbon-dioxide (CO_2) and water (H_2O).
- Only 3% of the water present on the continents is freshwater.
- Lentic systems derive most of their waters from rains, surface runoffs or from underground sources.
- The flow of water is unidirectional in a lotic water system.
- Wetlands are referred to as the ecotones or transitional zones between permanently aquatic and dry terrestrial ecosystems.
- Specific heat refers to the amount of heat required to raise the temperature of a 1-gram sample of a substance by one degree Celsius.
- Latent heat of fusion is the heat required by a specific quantity of the substance to change its state from a solid to a liquid, at constant pressure.
- Eurythermal organisms are those organisms which can withstand a wide range of temperature.
- Stenothermal organisms are those organisms that only survive in a narrow temperature range.
- Turbidity of water directly influences the penetration of light. It limits the penetration of light in the aquatic bodies.
- Point source pollution refers to contaminants or harmful/toxic compounds that enter into surface water via a fixed source such as a pipe or ditch.
- Nonpoint source pollution generally results from Surface run-off from agricultural fields (pesticides, chemicals, and fertilizers), overflowing small

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drains, precipitation, atmospheric deposition, or hydrological modification, rain water sweeping roads, etc.

- The pH value is defined as the effective concentration of ions present in water.
- A change in salinity of the freshwater bodies may adversely affects the growth, survival and reproductive capabilities of the organisms living in it.
- Approximately 1% of earth's water is found in lakes, but the renewal time is much more rapid than the ocean.
- Lakes also form in calderas, created by the collapse of volcanic craters
- Lakes can also be formed by the movement of the tectonic plates that form the Earth's crust.
- Artificial lakes are generally created by flooding land behind a dam. They are normally referred to as an impoundment or reservoir.
- Trophic conditions indicate the biological productivity of the lake.
- The biological productivity of oligotrophic lake is very low due to its low nutrient content. The water of such lakes is clear and highly transparent.
- Eutrophic lakes are those lakes which exhibits very high biological productivity.
- Hypereutrophic lakes are excessively rich in nutrients leading to algal blooms.
- Dystrophic lakes are rich in humic substances as well as organic acids, so the water is usually brown or tea-colored.
- Amictic lakes are permanently frozen lakes below 4 degree centigrade.
- A dimictic lake is a body of freshwater whose difference in temperature between surface and bottom layers becomes negligible twice per year.
- Apart from the natural lake, artificial lakes are constructed for diverse purpose like agricultural use, aesthetic, recreation, industrial use, hydro-electric power generation or domestic water supply.
- The littoral zone consists of the area from the dry land sloping to the open water.
- The Limnetic Zone is known as the open water area of the lake. Limnetic zone is much larger in oligotrophic lakes as compared to eutrophic or older bodies of water.
- Benthic Zone is the bottom of the lake. It consists of organic sediments and soil.
- The primary productivity through photosynthesis of littoral and limnetic zone is more due to greater penetration of light than the profundal zone.
- Streams are zones where a quick flow of shallow water creates a shearing stress on the stream bed, leading to a rocky or gravel substratum covered by fully oxygenated water.
- Most streams have highest discharge during winter rains, when particulate matters, nutrients like iron, sulphate, phosphate or nitrate are transported to different parts by the flow of the streams.

- Streams exhibits longitudinal zonation or profile instead of horizontal as seen in lakes and ponds.

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1.9 KEY TERMS

- **Physical limnology**: Physical limnology deals with the physical properties of freshwater bodies like lakes and rivers.
- **Lentic aquatic systems**: Lentic aquatic systems contain stagnant waters.
- **Lotic aquatic systems**: Lotic aquatic systems contain free flowing waters.
- **Wetlands**: Wetlands are referred to as the ecotones or transitional zones between permanently aquatic and dry terrestrial ecosystems.
- **Turbidity:** Turbidity refers to the measure of relative clarity of a liquid.
- **Dissolved Oxygen (DO):** Dissolved oxygen (DO) is the amount of oxygen that is present in water.
- **pH value:** It is defined as the effective concentration of ions present in water.
- **Lake:** Lake is a large water body of standing water occupying a basin which does not have any connection with sea.
- **Salt lakes:** Salt lakes are formed when there is no natural outlet or where the water evaporates and water become more salty.
- **Ox-bow lakes:** Ox-bow lakes are formed when slow-moving river forms a sinuous horseshoe bend like water body, which is detached from the main river via a narrow neck.
- **Crater lakes:** They are formed due to volcanic craters and calderas.
- **Eutrophic lakes:** Eutrophic lakes are those lakes which exhibits very high biological productivity.
- **Hypereutrophic lakes:** Hypereutrophic lakes are excessively rich in nutrients leading to algal blooms.
- **Polar lakes:** The surface temperature of polar lakes never falls below 4 degree centigrade.
- **Stream:** A stream can be defined as a body of water with a current, and is smaller than a river.
- **Spring:** A spring is referred to as a water resource formed when the side of a hill, a valley bottom or other excavation intersects a flowing body of groundwater at or below the local water table.
- **Artesian springs**: Artesian springs characteristically happen at the lowest point in a given area.
- **Karst springs**: Karst springs includes the largest discharges of groundwater from a single orifice.
- **Pond:** Pond is defined as a small, shallow inland stagnant water body which is smaller than a lake.

UNIT 2 CHEMICAL LIMNOLOGY

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Structure

2.0 INTRODUCTION

The chemical composition of water in aquatic ecosystems is influenced by natural characteristics and processes including precipitation, underlying soil and bedrock in the drainage basin, erosion, evaporation, and sedimentation. All bodies of water have a certain composition of both organic and inorganic elements and compounds. Biological reactions also affect the chemical properties of water. In addition to natural processes, human activities strongly influence the chemical composition of aquatic systems. The major focus of chemical limnology is on the cycling of various chemical substances in freshwater bodies like lakes and rivers. A lot of factors affect the chemistry of lakes and rivers like the chemical composition of the soil in the watershed, the atmosphere (mass of air surrounding Earth) as well as the composition of the riverbed or lake bottom.

Chemical limnology focuses on the cycling of various chemical substances in lakes and rivers. Several factors affect the chemistry of lakes and rivers including the chemical composition of the soil in the watershed, the atmosphere (mass of air surrounding Earth) and the composition of the riverbed or lake bottom.

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The major focus of chemical limnology is on the cycling of various chemical substances in freshwater bodies like lakes and rivers. A lot of factors affect the chemistry of lakes and rivers like the chemical composition of the soil in the watershed, the atmosphere (mass of air surrounding Earth) as well as the composition of the riverbed or lake bottom. In present era, anthropogenic activities have a huge influence on the chemistry of freshwater system. Chemical limnologists play an essential role in understanding these effects. For instance, construction work near lakes and rivers changes the erosion patterns, i.e., wearing away of soil and thus hugely influences the type of salts/chemicals that reach the water bodies. Due to excessive use of pesticide/insecticides/fertilizers in the agricultural fields, rainwater running into lakes, rivers contains these contaminants in huge quantities. The pH of water, i.e., the concentration of the hydronium ions in water, is one of the most important aspect. Presence of hydronium ions in the water indicates the acidity (charge) of the water, which strongly affects the kind of flora or fauna that can inhabit the water bodies. Other important substances are the sulphate and nitrate ions, which become concentrated in freshwaters as a result of acid rain. Also, the heavy metals like mercury (Hg) are dangerous pollutants that can circulate in the water and affect the health of animals, along with the humans who eat those animals and use the lake or river. Fresh water (or freshwater) is any naturally occurring water containing low concentrations of dissolved salts and other total dissolved solids. Freshwater habitats occupy a relatively small portion of earth‘s surface as compared to marine and terrestrial habitats. As depicted in the figure, 97% of the earth’s water is in the oceans or sea as is referred to as saline water. Only 3% of the water present on the continents is freshwater.

A biogeochemical cycle is the pathway by which a chemical substance cycles (is turned over or moves through) the biotic and the abiotic compartments of Earth. The biotic compartment is the biosphere and the abiotic compartments are the atmosphere, hydrosphere and lithosphere. There are biogeochemical cycles for chemical elements, such as for calcium, carbon, hydrogen, mercury, nitrogen, oxygen, phosphorus, selenium, iron and sulphur, as well as molecular cycles, such as for water and silica.

In this unit you will study about the kinetics and distribution of oxygen in freshwater, salinity in inland water, biogeochemical cycles, Silicon, Iron and Manganese, Nitrogen, phosphorous and Sulfur cycles in freshwater system, and the productivity of freshwater system.

2.1 OBJECTIVES

After going through this unit you will be able to:

- Understand the kinetics and distribution of oxygen in freshwater
- Explain the salinity in inland water
- Comprehend different biogeochemical cycles
- Elaborate on the process and importance of Silicon, Iron and Manganese Nitrogen, phosphorous and Sulfur cycles in freshwater system
- Analyze the productivity of freshwater system

2.2 KINETICS AND DISTRIBUTION OF OXYGEN IN FRESHWATER SYSTEM

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DO is the abbreviation used for Dissolved Oxygen. Dissolved oxygen characterizes the concentration of oxygen in an aqueous solution and refers to the free oxygen dissolved in water. The unit of dissolved oxygen is mg/L, expressed in milligrams of oxygen per litre of water. The amount of dissolved oxygen in the water is an indicator of the self-purification ability of the water body. High dissolved oxygen is conducive to the degradation of various pollutants in the water body, so that the water body can be purified faster; on the contrary, when the dissolved oxygen is low, the pollutants in the water body degrade slowly. Figure 2.1 is depicting the oxygen supply and consumption in a river system.

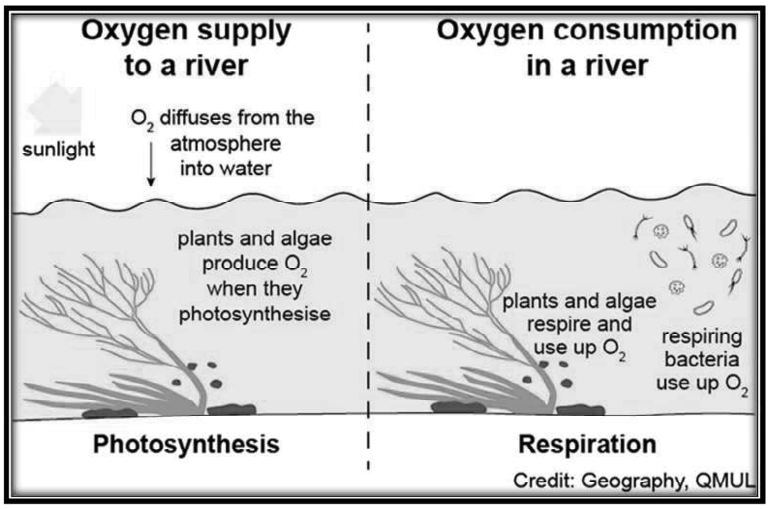

Fig. 2.1 *The Oxygen Supply and Consumption in a River System*

Factors Affecting Dissolved Oxygen

The concentration of oxygen in inland waters depends upon factors within the water. Oxygen is released into the water bodies by biological production or in simple terms by the process of photosynthesis carried out by autotrophs as well as by simple aeration methods, i.e., passage of oxygen through the air-water interface, however, dissolved oxygen is consumed by the process of biological decay and advanced metabolism oxygen consumption. The flow of these two effects makes the dissolved oxygen content in water show temporal and spatial changes. Environmental factors affecting the content of dissolved oxygen in water include water temperature, oxygen partial pressure, salinity and other factors. All these factors are discussed below:

(1) **Temperature of the Water-** Numerous chemical reactions operating within the lake system also affect the concentration of Dissolved Oxygen (DO). The main source is the passage of oxygen through the air-water interface, which is affected principally by the factors such as lake temperatures. At low temperatures, the partial pressure of Dissolved Oxygen (DO) in water is reduced. Therefore, during winter seasons, especially when vertical

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mixing is greatly improved due to lack of thermal structure and increased wind stirring, lakes are replenished with oxygen. However, at very low temperature during winters, a speedy formation of ice or the formation of strong winter thermal stratification may significantly prevent the replenishment of oxygen. In the hot seasons (at increased temperatures), even though surface waters may remain comparatively saturated and even supersaturated, the concentrations of the dissolved oxygen remain lower. Below the surface, consumption of oxygen via biological decay may cause serious depletion. Thus, in tropical regions, there is huge dependency on the occasional occurrence of cold spells or on significant night-time cooling to promote oxygen replenishment. Deep lakes in such tropical regions are often found to be anoxic (lacking in oxygen) especially in the deeper portions. Figure 2.2 is depicting the DO (Dissolved oxygen curve) at summer and winter.

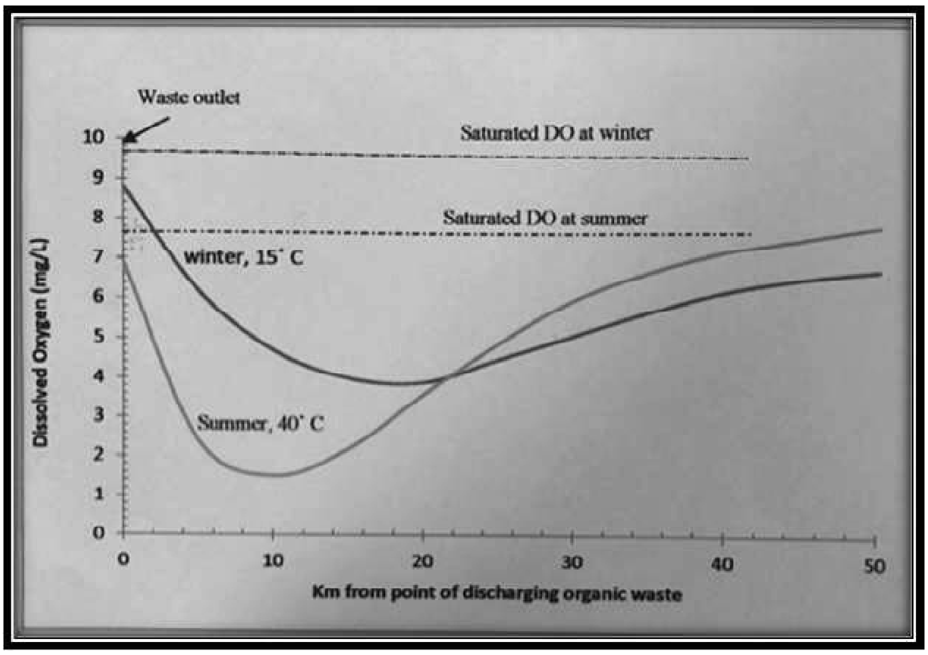

Fig. 2.2 *DO (Dissolved Oxygen Curve) at Summer and Winter*

(2) **Salinity of Water-** Further, Dissolved Oxygen (DO) levels of a lake/estuary changes with salinity level. The amount of oxygen that can dissolve in water, or solubility, decreases as salinity increases. For instance: the solubility of oxygen in seawater is approximately 20 percent less than it is in fresh water at the same temperature.

(3) **Partial Pressure of Oxygen-** When the salt content of the water temperature is constant, the saturated salt content of dissolved oxygen in the water increases with the increase of the oxygen partial pressure on the liquid surface.

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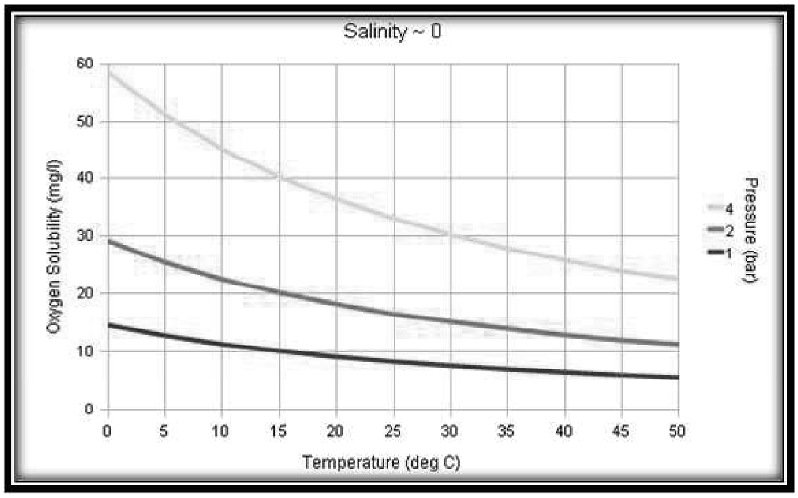

Fig. 2.3 Solubility of Oxygen in Freshwater System

Figure2.3 illustrate the solubility of oxygen in freshwater system.

(4) The stratification of water temperature and growth of phytoplankton were the key factors determining the vertical distribution of dissolved oxygen. Chlorophyll 'a' was positively associated with water temperature as well as pH, whereas it is negatively associated with turbidity of water, signifying that the vertical dispersal of phytoplankton was chiefly affected by the attenuation of light intensity along the water depth and the stratification of water temperature.

Source: Yang F, Ji DB, Wang LJ, Li H, Li YJ. [Vertical Distribution Characteristics of Dissolved Oxygen and Chlorophyll a in Typical Tributaries during the Impoundment Period of the Three Gorges Reservoir]. Huan Jing Ke Xue. 2020 May 8; 41(5):2107-2115. Chinese. doi: 10.13227/j.hjkx.201909026. PMID: 32608828**.**

Dissolved Oxygen as an Indicator of Water Quality

At any particular time, inland waters may have a biological or chemical potential for oxygen utilization. Measurements of this are referred to as BOD (Biological Oxygen Demand) or COD (Chemical Oxygen Demand) respectively. These concepts serves as a partial indicators of the water quality. For instance:

Dissolved Oxygen (DO) level helps to determine the amount of organic matter present in water:

Oxygen gas is absorbed by the water from the atmosphere but it is being consumed by organic matter present in it. Therefore, if the oxygen gas present in water is lower than its normal saturation level, it indicates the presence of organic matter which makes the water unsuitable for consumption. The excessive growth (or bloom) of algae and plankton in a water body are indicators, i.e., eutrophication is considered to be a serious environmental matter as it often leads to the deterioration of water quality and the depletion of dissolved oxygen in aquatic bodies. Eutrophic waters can eventually become 'dead zones' that are no longer capable of supporting aquatic life (both plants and animals). Over a period of time, anthropogenic activities like use of excessive fertilizers in agricultural field, disposal of nutrient rich waste into water bodies etc. has increased the nutrient

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content of freshwater bodies ultimately leading to the deterioration of water quality and making it unfit for human consumption. Figure 2.4 is depicting the process of eutrophication.

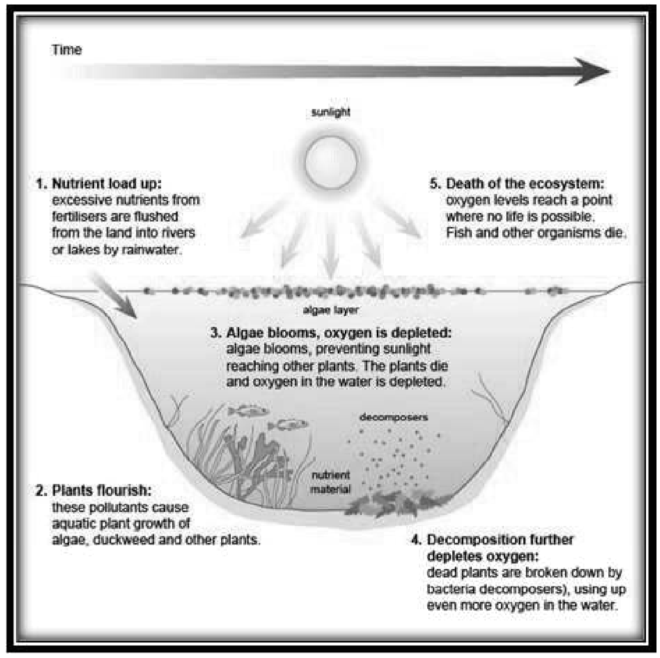

Fig. 2.4 *Process of Eutrophication*

Accidental spillage of oil in water bodies/release of oil based industrial pollutants in water bodies.

Oil spills leads to the formation of a thick layer on the surface of water. This thick oil layer can stop marine plants from receiving enough light for carrying out the process of photosynthesis as well as it can disturb the free flow of oxygen in the water. This severely affects the floral and faunal biodiversity.

Biological Oxygen Demand (BOD)

Biological Oxygen Demand (BOD) or Biochemical Oxygen Demand (BOD) is referred as the amount of oxygen needed or demanded by aerobic microorganisms to break down the organic matter present in a certain sample of water at a specific temperature over a given period of time. BOD of water sample is evaluated by measuring the oxygen consumed by the bacteria from the decomposition of organic matter over a period of five days at a specific temperature of 20 degree Celsius. A lot of factors influence the BOD of water like temperature, pH of the water sample, inorganic substance present in the water, kind of aerobic microorganisms present in water, amount and type of organic matter present in the water sample etc. BOD values indicate the polluting potential of water. A BOD value of less than 1mg/L indicates pure drinking water, BOD value between 2-8mg/L indicates moderately polluted water whereas a BOD value greater than 8mg/L indicates severely polluted water unfit for consumption. BOD finds its prime significance in sewage treatment plants. It indicates the respiration rate in sludge, soil, garbage, etc. Table 2.1 depicting the BOD level and corresponding water quality.

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Table 2.1 *BOD Level and Corresponding Water Quality*

BOD Level (in ppm)	Water Quality
1 - 2	**Very Good** There will not be much organic waste present in the water supply.
3 - 5	**Fair: Moderately Clean**
6 - 9	**Poor: Somewhat Polluted** Usually indicates organic matter is present and bacteria are decomposing this waste.
100 or greater	**Very Poor: Very Polluted** Contains organic waste.

Chemical Oxygen Demand (COD)

The chemical oxygen demand (COD) represents the amount of oxygen necessary for the aerobic biological oxidation (breakdown) of the organic substances in a given water body or sample to carbon dioxide (CO_2) and water (H_2O) if the organics are actually biodegradable. COD measurements are important in accessing the quality of a given water body. COD values helps us to determine the extent of pollution that the water has undergone. COD tests also assess the amount of inorganic contaminants that is dissolved or suspended in a water body. Thus, it can be concluded that higher the COD, higher is the contamination level of water. The COD test usually involves a very strong oxidizing chemical agent like potassium dichromate ($Cr_2O_7^{2-}$). The primary basis for the COD test is that nearly all organic compounds can be fully oxidized to carbon dioxide with a strong oxidizing agent (e.g. $Cr_2O_7^{2-}$) under acidic conditions. Silver compounds can also be involved in the COD test to speed up the oxidation of certain organic compounds. Mercury can also be used in the COD test to reduce the interference from oxidation of chloride ions. Figure 2.5 is depicting the COD test.

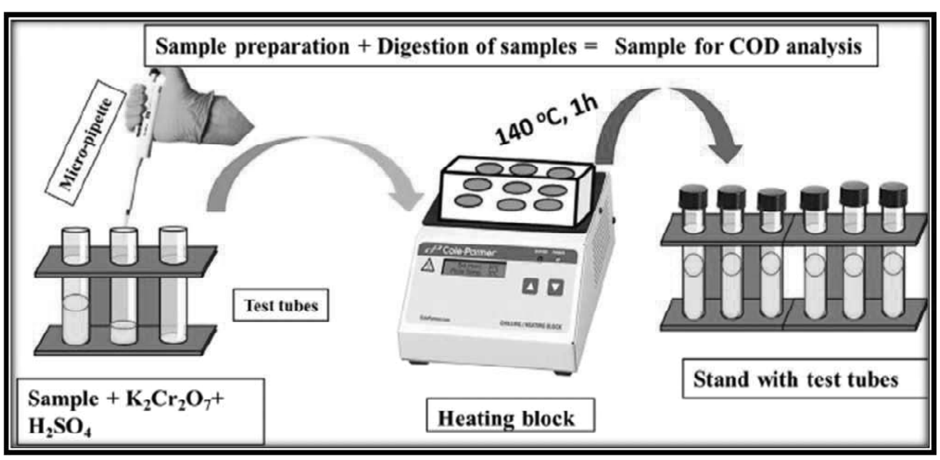

Fig. 2.5 *COD Test*

2.3 SALINITY IN INLAND WATER

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'Inland waters' are aquatic-influenced environments located within land boundaries. This includes those located in coastal areas, even those adjacent to marine environments. Inland water systems can be fresh, saline or a mix of the two (brackish water). Inland waters include lakes, rivers, ponds, streams, groundwater, springs, cave waters, floodplains, as well as bogs, marshes and swamps, which are traditionally grouped as inland wetlands. The inland waters which include both fresh water masses and estuarine waters of varying salt content are clearly distinguishable from the salt waters of the oceans. The inland water masses are discrete and being isolated within the specific land area, acquire the characteristic chemical composition of the land, by exchange between soil and water. Under laboratory conditions, pure water contains only oxygen and hydrogen atoms, however in reality, many substances are often dissolved in water, like salt. Salinity refers to the total concentration of the ions present in lake water and is generally evaluated from the concentration of sodium (Na), potassium (K), magnesium (Mg), calcium (Ca), carbonate, silicate as well as halide concentrations. Overall, it has been observed that among positively charged ions (cations), calcium concentrations is the highest, followed by magnesium, sodium, and potassium. Among the major negatively charged ions (anions), carbonate is generally the most abundant, followed by sulphate and chloride. Numerous significant bodies of inland waters, usually referred to as inland seas exhibit very high salinities. For instance:- Great Salt Lake, in Utah, has a salinity of around 200,000 milligrams per litre, as compared with Lake Superior's value having a salinity of about 75 milligrams per litre whereas an estimated mean for all rivers of around 100 to 150 milligrams per litre. These ions are progressively introduced to lakes from rivers as well as rainwater, where they keep on concentrating due to evaporative loss of relatively pure water. Further, nutrients like phosphate, nitrate, and silicate, heavy metals like mercury, manganese, copper, lead, and polychlorinated hydrocarbons like DDT have fascinated due to their role in ecological problems. Over a period of time, anthropogenic activities like use of excessive fertilizers in agricultural field, disposal of nutrient rich waste (rich in phosphates/sulphates/nitrates content) into water bodies, etc., has increased the nutrient content of freshwater bodies ultimately leading to the deterioration of water quality and making it unfit for human consumption. Such lakes are referred to as hypereurotrophic lakes/ponds are excessively rich in nutrients leading to algal blooms. Algal blooms lead to reduced dissolved oxygen levels resulting in a low-depth death zone beneath the surface of such a reservoir, which reduces the density of the organism.

Contribution of Other Ions to Salinity in Inland Waters:

(1) Sulphate is one of the major ions in lake waters. Under anaerobic conditions, in which bacteria persist in the oxidation of biological material, hydrogen sulphide is produced. Further, hydrogen sulphide occurs, when anoxic situations happen in the deep waters just above the sediments, and the water is sufficiently acidic to precipitate the iron present.

(2) Nitrogen and its various compounds appears in different forms in freshwater bodies like free nitrogen in solution, organic compounds, ammonia, nitrite as well as nitrate.

(3) Phosphorous is an essential component of biomolecules like ADP and ATP, nucleic acids, phospholipids (membranes), apatite (bones and teeth), etc. Orthophosphate and various organic phosphates are the most important phosphorous compounds in lakes. Phosphates can enter into the aquatic system via precipitation, dust in air, groundwater, adsorbs to soil particles or surface runoff. Presence of high phosphates and nitrates in the upper portion of lakes promotes the growth of phytoplankton. In one of the study conducted (oceanographer *Redfield* in the 1950's), Phosphorous is considered to be the most limiting nutrient in the fresh-water system because the amount of phosphorous available to organisms is much less than the amount required when compared to other elements. Figure 2.6 is depicting the lake Chemistry-Phosphorous.

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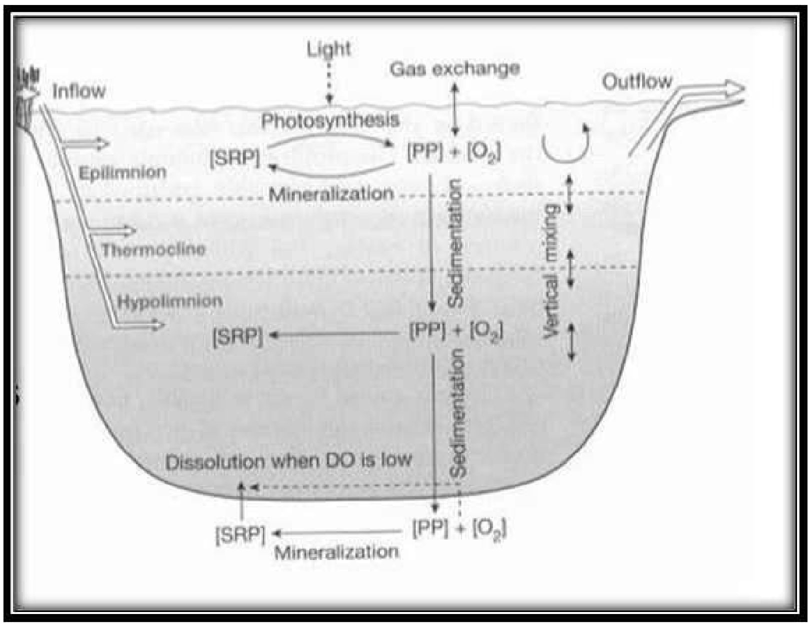

Fig. 2.6 *Lake Chemistry-Phosphorous*

4) Silica is also present in lake waters along with other nutrients. It is introduced in influents and to some extent from the sediments. The production of diatom blooms is a major process for reducing silicate concentrations.

2.3.1 Types of Salinity

There are 2 major types of salinity:

1) Primary: Primary salinity refers to naturally occurring salinity. Primary salinity occurs naturally in soils and waters. Examples of naturally occurring saline areas include salt lakes, salt pans, salt marshes and salt flats.

(2) Secondary: Secondary salinity refers to salinity resulting from anthropogenic activities usually land development and agriculture.

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Salinity in Coastal Areas

Further, in coastal areas, it has been observed that fresh water may contain significant concentrations of salts derived from the sea if windy conditions have lifted drops of seawater into the rain-bearing clouds. This phenomenon can elevate concentrations of ions like sodium, magnesium, sulphate and chloride.

Salinity in Desert Areas

In desert areas, rain-bearing winds can pick up sand and dust and this can be deposited somewhere else in precipitation then causing the freshwater flow to be significantly contaminated not only by insoluble solids but also by the soluble constituents of those soils. Further, several research studies indicates that significant amount of iron may be transported in this way.

Salinity in Estuaries

Estuaries form a transition zone between river environments and maritime environments and are an example of an ecotone. Salinity in an estuary varies according to the location of the estuary, the daily tides as well as the volume of fresh water flowing into the estuary. In estuaries, salinity levels are highest near the mouth of a river where the ocean water enters, and lowest upstream where freshwater flows in. Further, level of salinity keeps on changing in accordance with the tidal cycle. For instance: salinity levels in estuaries rise during the summer as high temperature leads to greater evaporation whereas it declines during spring as freshwater keeps on flowing from streams as well as groundwater due to rainfalls.

Estuarine organisms respond differently to varying salinities. Many benthic organisms such as oysters and crabs, can tolerate some change in salinity, however salinities outside an acceptable range will negatively affect their physiological process like growth as well as reproduction, and ultimately, their survival.

Further, dissolved oxygen levels of an estuary changes with salinity level. The amount of oxygen that can dissolve in water, or solubility, decreases as salinity increases. For instance: the solubility of oxygen in seawater is approximately 20 percent less than it is in fresh water at the same temperature.

2.3.2 Saline Lakes

Those lakes that have salinities in excess of 3 grams per litre are called as Saline lakes. Saline lakes comprises the largest lake in the world i.e. the Caspian Sea; the lowest lake, i.e., the Dead Sea; and numerous of the highest lakes like those in Tibet and on the Altiplano of South America. Even though, inland saline water consists of some 45% of total inland water, however, it is mainly concentrated in only a few deep lakes, chiefly the Caspian Sea. Saline lakes are commonly seen in the semiarid regions of the biosphere, which include around 27 percent of total land area due to two reasons: Firstly, a balance between input of water (precipitation and inflows) vs output of water (evaporation and seepage) and secondly the presence of endorheic drainage basins.

All salt lakes have characteristic property, i.e., salt content of saline lakes is much higher when compared to other freshwater bodies and also the ionic composition of saline lakes is different from those of freshwater bodies. Depending upon the ionic composition as well the dominant ion present, salinities of saline lakes may reach values above 300 grams per litre. In permanent, deep salt lakes, annual salinities as well as water level varies slightly , however, in shallow, temporary lakes, salinities may range from less than 50 grams per litre to more than 300 grams per litre over a span of single year with wide water level fluctuation. Salinity has many direct effects on other physicochemical features like on freezing points. It also affects the amount of oxygen that can be dissolved at a given temperature.

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2.3.3 Effects of Salinity in Freshwater System

Salinity in freshwater has several impacts like:

- Salinity affects crop production, pastures as well as trees by interfering with nitrogen uptake, reducing growth and stopping plant reproduction. All irrigation water contains some salts, which generally persist on the soil surface or on leaves of plants after evaporation. Therefore, irrigation with water having high salt concentration has the potential to deliver an increased amount of salt to the soil.
- Some ions like chloride are highly toxic to plants and as the concentration of these ions increases, the plant dies due to toxicity.
- Salinity affects the quality of water for drinking, human consumption as well as for agricultural purposes, with severe economic, social and environmental consequences for both rural and urban communities.
- Sodium and magnesium sulphate levels in drinking water may produce a laxative effect and can also reduce the suitability of a water supply for grazing animals.
- Salt interacts with in-stream biota (animals and plants), changing the ecological health of streams and estuaries. Salinities outside an acceptable range will negatively affect the physiological process like growth as well as reproduction, and ultimately, the survival of organisms residing in it.
- High salinity acts as greatest threat to biodiversity as it can lead to loss of habitat for numerous organism.
- Further, dissolved oxygen levels of an estuary changes with salinity level. The amount of oxygen that can dissolve in water, or solubility, decreases as salinity increases.For example the solubility of oxygen in seawater is approximately 20 percent less than it is in fresh water at the same temperature.
- Dry land salinity is closely linked to other soil degradation issues, including soil erosion. Salinity is often associated with prolonged wetness and lack of surface cover and therefore increases the vulnerability of soils to erosion.
- In desert areas, rain-bearing winds can pick up sand and dust and this can be deposited somewhere else in precipitation then causing the freshwater flow to be significantly contaminated not only by insoluble solids but also by the soluble constituents of those soils.
    a. Salinity adversely affects the biota of an aquatic body and hence may also indirectly affect people by reducing the quality of the natural environment (for example, where the numbers and variety of wildlife decrease in salinized natural wetlands).

- Road and bridge damage caused by shallow, saline groundwater is a major cost and many towns also experience damage to footpaths, parks, sewage pipes, housing and industry.

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Check Your Progress

1. What is the major focus of chemical limnology?
2. What is dissolve oxygen?
3. Define biological oxygen demand.
4. What do you understand by the term inland water?
5. How the salinity of water is evaluated.
6. Why Phosphorous is considered to be the most limiting nutrient in the fresh-water system?
7. Define secondary salinity.

2.4 BIOGEOCHEMICAL CYCLES IN FRESHWATER SYSTEM

A biogeochemical cycle is referred to as the pathway via which a chemical substance is turned over or moves through the biotic (biosphere) and the abiotic (lithosphere, atmosphere and hydrosphere) compartments of Earth. The important biogeochemical cycles are: calcium cycle, carbon cycle, hydrogen cycle, mercury cycle, nitrogen cycle, oxygen cycle, water cycle, phosphorus cycle, selenium cycle, iron cycle, silica cycle, sulphur cycle as well as rock cycle. A few characteristics of biogeochemical cycles are as follows:

- Biological Chemical + Geological Process= Biogeochemical
- Energy flows via an ecosystem and is released as heat, however chemical elements are recycled.
- The ways in which an element or compound moves between its numerous biotic and abiotic forms and locations in the biosphere is referred to as biogeochemical cycle. Precisely, it can be defined as movement of nutrients as well as other elements between living and non-living components of ecosystem.
- Sun is the primary source of energy on earth. Life on earth comprises a great variety of living organisms. These living organisms occur and survive in a diversity of associations. Such survival encompasses the presence of systemic flows such as flows of energy, water as well as nutrients.
- The balance of the chemical elements is preserved by a cyclic movement through the tissues of plants and animals.
- The cycle begins by absorbing the chemical elements by the organism and is returned to the atmosphere, hydrosphere or lithosphere via decomposition. These cycles are mainly energized by solar insolation.

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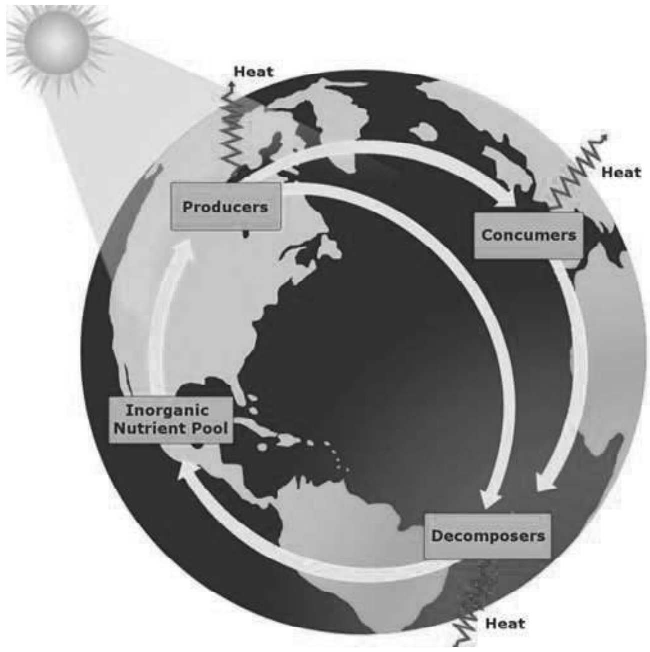

Fig. 2.7 *Basic Concept of Biogeochemical Cycle*

Figure 2.7 depicts the basic concept of biogeochemical cycle.

2.4.1 Types of Biogeochemical Cycles

There are two types of biogeochemical cycles.

(1) The Gaseous Cycle

In the gaseous cycle, the main reservoir of nutrients is either the atmosphere or the hydrosphere (ocean). For instance: nitrogen, oxygen, carbon and water cycles are gaseous cycles. Figure 2.8 is depicting the gaseous cycle (oxygen) operating in atmosphere.

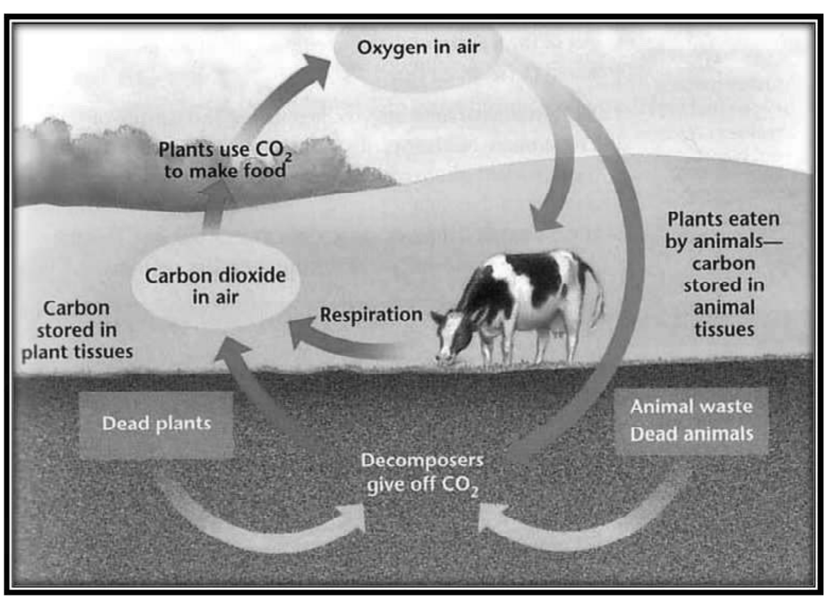

Fig. 2.8 *Gaseous Cycle (Oxygen) Operating in Atmosphere*

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(2) The Sedimentary Cycle

In the sedimentary cycle, the main reservoir is the lithosphere and the sedimentary as well as other rocks of the earth's crust. For instance: iron, calcium, phosphorus, and other more earthbound elemental cycles are sedimentary cycles. Figure 2.9 is depicting the generalized sedimentary cycle.

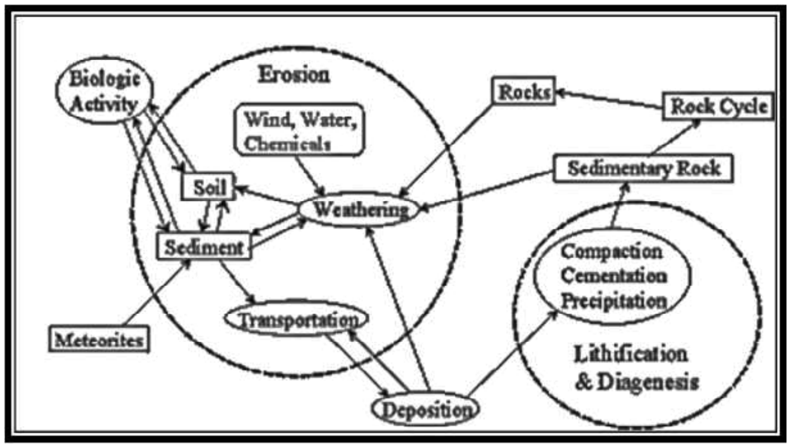

Fig. 2.9 Generalized Sedimentary Cycle

Input of Nutrients (Addition) to the Ecosystem

Nutrients enters into the ecosystem by following four ways:

(a) Rock Weathering

Essential nutrients added to the ecosystem by this process are: Calcium (Ca), magnesium (Mg), potassium (K), sodium Na), silicon (Si), iron (Fe), aluminium (Al), and phosphorus (P).

(b) Atmospheric Inputs

Atmosphere adds nutrients to the ecosystem via a number of biological processes like carbon is absorbed by the process of photosynthesis, sodium and potassium deposited via precipitation.

(c) Biological Nitrogen Fixation

This process is majorly for the fixation of nitrogen and it is carried out by number of organisms like several species of bacteria, a few actinomycetes (fungi) and blue-green algae (cyanobacteria).

(d) Immigration

Migration and subsequent death of the organism can add significant nutrients to the ecosystem.

Output of Nutrients (Loss) from Ecosystem

(a) Erosion

Soil erosion leads to removal of top most layer of soil rich in essential nutrients.

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(b) Leaching

Leaching occurs when water flowing vertically through the soil transports nutrients in solution downward in the soil profile. The process can leads to loss of essential nutrients.

(c) Gaseous Losses

Gaseous loss of nutrients can occur when specific environmental conditions promote the export of nutrients in a gaseous form.

(d) Emigration and Harvesting

Emigration of animals and the removal of vegetation can also leads to huge loss of nutrients. Figure 2.10 illustrates the flow of nutrients in an ecosystem.

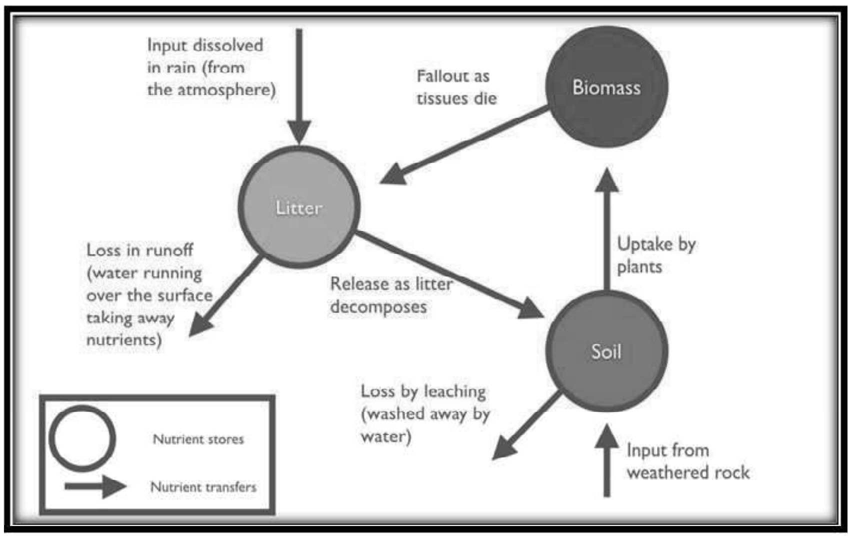

Fig. 2.10 *Flow of Nutrients in an Ecosystem*

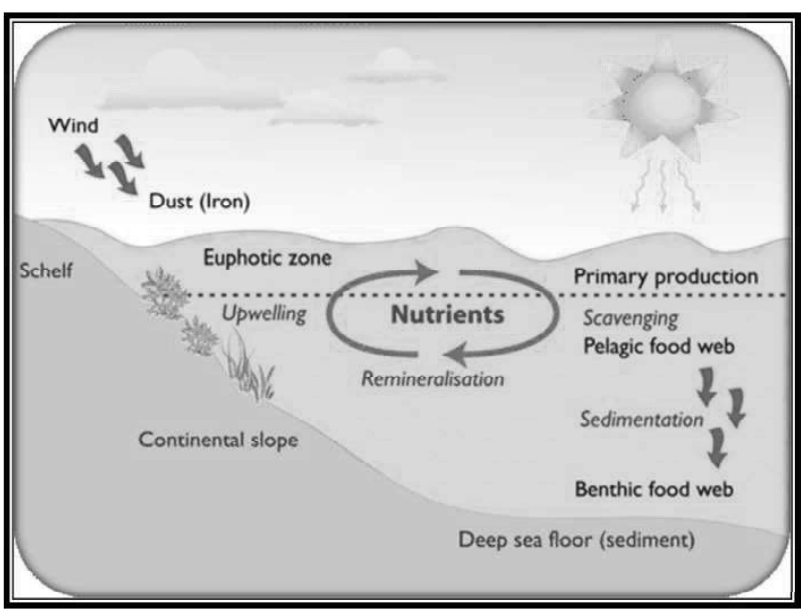

Fig. 2.11 *Nutrient Cycle via Aquatic Ecosystem*

Figure 2.11 depicts the nutrient cycle via aquatic ecosystem.

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2.4.2 Types of Nutrient Flow in Ecosystem

Two major types of system are as follows:

(1) Closed System- In the Closed system, chemicals or elements used in the ecosystem are recycled instead of being lost. Figure 2.12 is depicting the closed type of nutrient flow in ecosystem.

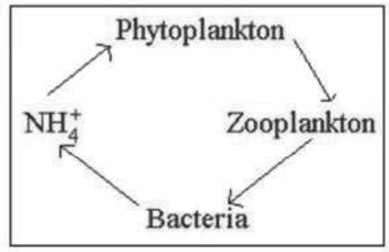

Fig. 2.12 *Closed Type of Nutrient Flow*

(2) **Open System:** In the open system, chemicals or elements tend to flow in and out of the system. Figure 2.13 depicts open type of nutrient flow in ecosystem**.**

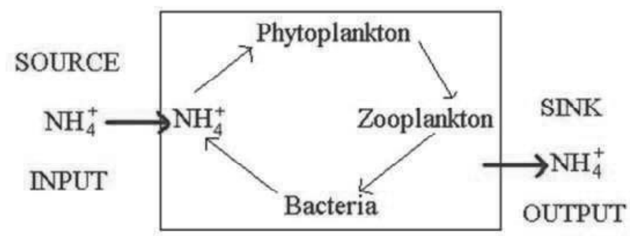

Fig. 2.13 *Open Type of Nutrient Flow*

2.5 SILICON CYCLE IN FRESHWATER SYSTEM

Silicon is known to be the second most abundant element in the Earth's crust, 27% by weight (Faure, 1986), exceeded only by oxygen. In natural environments, silicon is most stable in various forms of solid, silicon dioxide (silica, SiO_2), as mineral silicates and as well as the dissociated anions of silicic acid (H_4SiO_4). Silica forms the skeleton structures of numerous aquatic plankton like diatoms, radiolarians as well as the spicules of sponges. Hence, silica controls primary production in aquatic systems as well as its cycling is controlled by the interplay between biological and physiochemical processes. Silica enters into the aquatic environments by weathering of rock-forming silicate minerals by acidic dissolution. Biological uptake of silica by organisms depletes the surface waters with respect to silica. When these planktonic organisms die, their silica skeletons sink and starts dissolving.

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Diatoms are present extensively in freshwater system. They are enclosed in skeleton made up of silica having two perforated valves. The dissolution of biogenic silica in aquatic systems happens when diatom skeleton or skeleton composed of silica is exposed to under saturated water. The rate of dissolution depends upon aquatic factors like temperature, pH, etc. Further, several microbial species can significantly increase the rate of dissolution of biogenic silica by releasing enzymes. The destruction, degradation as well as solubilisation of mineral silicates is highly influenced by microbial activity. Biofilms of free-living microbes like algae, lichens, fungi, prokaryotes living on the or within prokaryotes, fungi, and algae, as well as lichens, living on and within influence the rate as well as mechanism of physical and chemical weathering of siliceous rocks. The amount of dissolved silica present in aquatic environment controls the composition and abundance of planktonic diatoms. Figure 2.14 shows the silicon cycle.

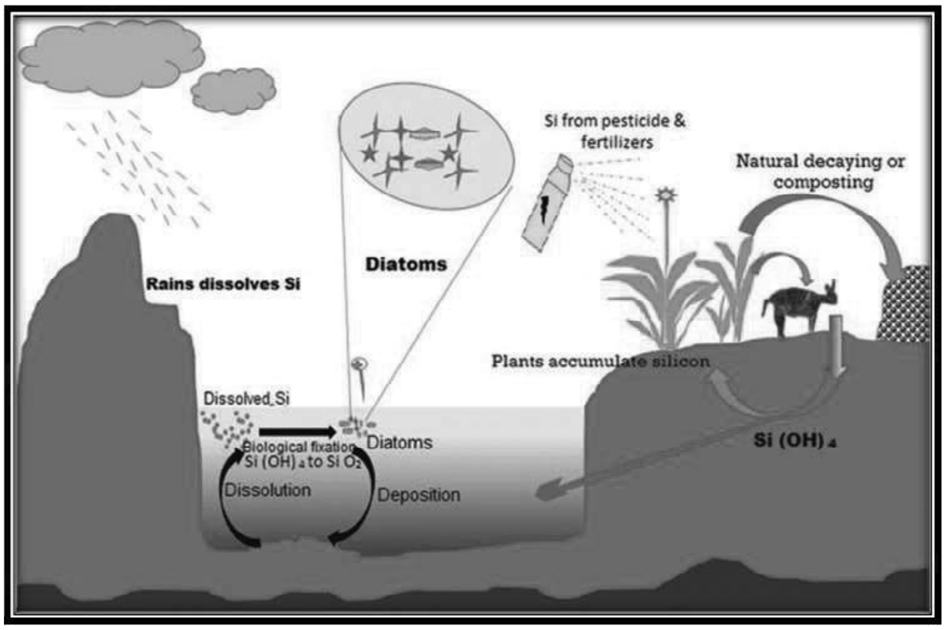

Fig. 2.14 *Silicon Cycle*

2.5.1 Iron Cycle in Freshwater System

Iron is an essential micronutrient for almost every life form present on earth. It is a crucial constituent of haemoglobin, vital to nitrogen fixation as part of the nitrogenise enzyme family, as well as part of the iron-sulphur core of ferredoxin. It facilitates the process of electron transport in chloroplasts, eukaryotic mitochondria and bacteria. Due to the high reactivity of Fe^{2+} with oxygen and low solubility of Fe^{3+}, iron is a limiting nutrient in aquatic environment and affects the growth of phytoplankton. The iron cycle (Fe) is the biogeochemical cycle of iron via the atmosphere, hydrosphere, biosphere and lithosphere. Iron is suspended as sediment particles in rivers. Generally, iron is available as an inorganic source to phytoplankton; however, organic forms of iron can also be utilized by specific diatoms. Uptake of iron by phytoplankton lowers down iron concentrations in surface seawater. Remineralisation, happens when the sinking phytoplankton are degraded by zooplankton as well as bacteria. Iron chiefly is present in particulate phases as ferric iron, and the dissolved iron fraction is removed out of the water column by coagulation.

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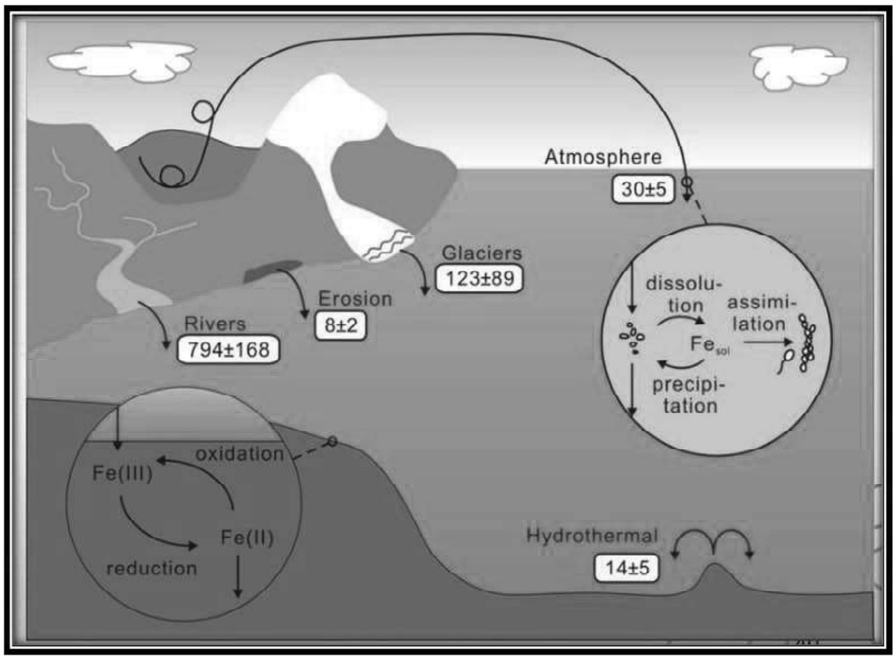

Fig. 2.15 *Iron Cycle*

Figure 2.15 illustrate the Iron cycle. The iron cycle influences other cycles like nitrogen, phosphorous as well as sulphur cycles. Soluble Fe_2 can act as the electron donor, reducing oxidized organic as well as inorganic electron receptors, including O_2 and NO_3, and become oxidized to Fe_3.The oxidized form of iron can then act as the electron acceptor for reduced sulphur, H_2, and organic carbon compounds. This returns the iron to the oxidized Fe_2 state, completing the cycle. This transition of iron between Fe_2 and Fe3inside aquatic environments influences the freshwater phosphorus cycle. Fe_2 gets oxidized to Fe_3in the presence of oxygen (present in aquatic system). The reaction can be achieved either abiotically or biotically, i.e., by microbes via lithotrophic oxidation. Fe_3 can form iron hydroxides, which has the potential to bind tightly to phosphorus, removing it from the bioavailable phosphorus pool, and hence limiting the primary productivity of the aquatic system. Under anoxic conditions, Fe_3 can be reduced, used by microbes to be the final electron acceptor from either organic carbon or H_2. This lead to the releases of phosphorus back into the aquatic system for biological use. Iron influences sulphur cycle too. For instance: Green and purple sulphur bacteria can utilize Fe_2 as an electron donor during anoxic photosynthesis. Sulphate reducing bacteria under anoxic environments can reduce sulphate to sulphide, which then binds to Fe_2 to form iron sulphide. Iron sulphide is a solid mineral that can easily precipitates out of water and removes the iron as well as sulphur. Sulphide can reduce Fe_3 from iron that is previously bound to phosphate when there are no additional metal ions accessible, which releases the phosphate leading to the formation of iron sulphide. Iron plays a significant role in the nitrogen cycle, apart from its role as part of the essential enzymes involved in the process of nitrogen fixation. Under anoxic conditions, Fe_2 can donate an electron that is accepted by

NO_3^- which is oxidized to several different forms of nitrogen compounds, NO_2^-, N_2O, N_2, and NH_4^+, while Fe_2 is reduced to Fe_3. Figure 2.16 depicts the oxidation of Iron

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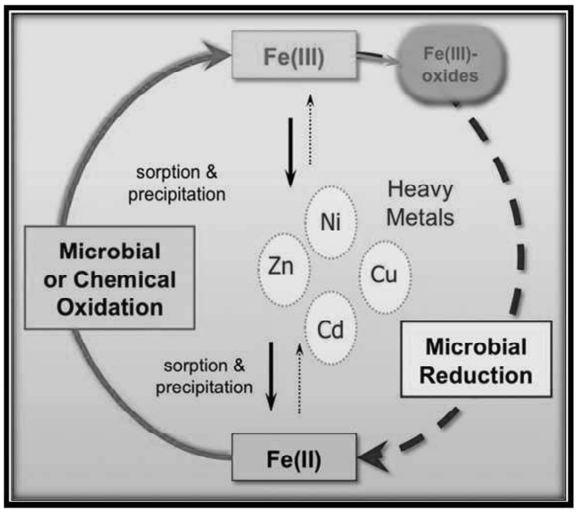

Fig. 2.16 *Oxidation of Iron*

2.5.2 Manganese Cycle in Freshwater System

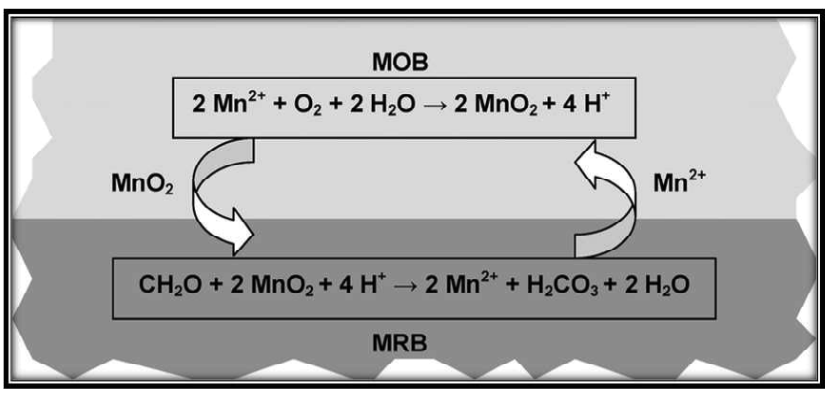

Fig. 2.17 *Reaction Manganese Cycle*

Figure 2.17 is depicting the reaction of manganese cycle in freshwater system.

The manganese cycle is the biogeochemical cycle of manganese via the atmosphere, hydrosphere, biosphere and lithosphere. There are bacteria that oxidise manganese to insoluble oxides, and others that reduce it to Mn^{2+} in order to use it Manganese cycle occur in a sediment-water system. The manganese oxidation is performed by manganese oxidizing bacteria (MOB) in an oxic zone, while the manganese reduction is performed by manganese reducing bacteria (MRB)-with concomitant oxidation of organic matter-in an anoxic zone.

Source:- Minireview: The Potential of Enhanced Manganese Redox Cycling for Sediment Oxidation Liesje De Schamphelaire, Korneel Rabaey, Nico Boon, and Willy Verstraete Laboratory of Microbial Ecology and Technology (LabMET), Ghent University, Coupure Links 653, B-9000 Ghent, Belgium. Figure 2.18 shows the manganese cycle

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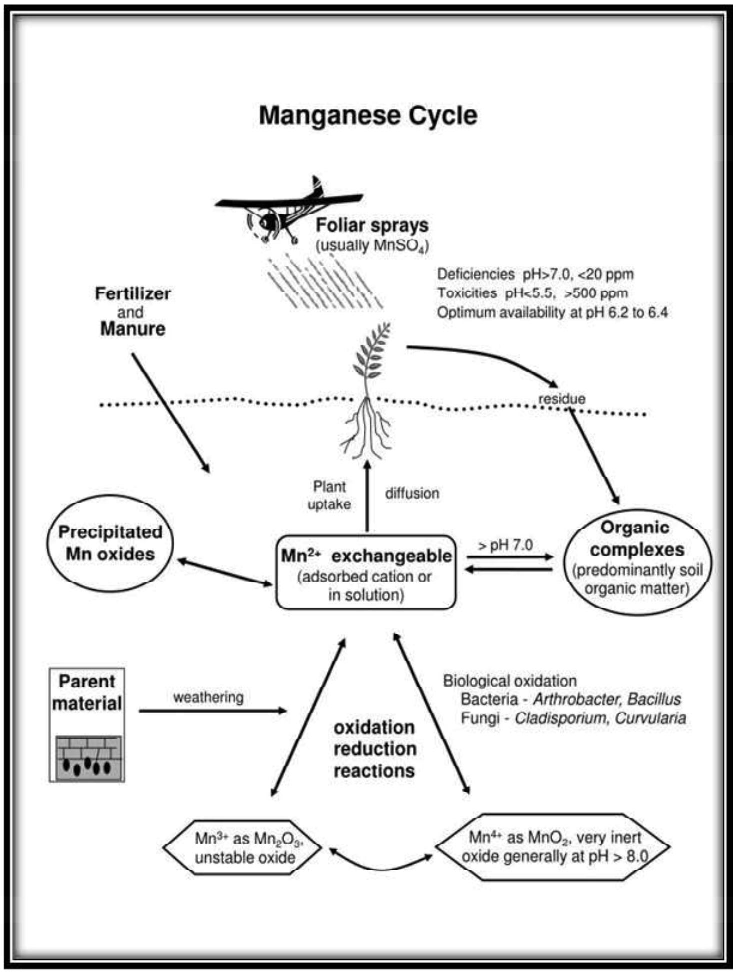

Fig. 2.18 *Manganese Cycle*

2.6 NITROGEN CYCLE IN FRESHWATER SYSTEM

Nitrogen is vital for several processes and is crucial for life on Earth. The nitrogen cycle is the biogeochemical cycle by which nitrogen is converted into multiple chemical forms as it circulates among atmosphere, hydrosphere and lithosphere. Nitrogen Cycling in aquatic Ecosystem can be divided into five phases:

(1) Nitrogen Fixation- Nitrogen fixation refers to the conversion of N_2 to ammonia or related nitrogenous compounds, by Blue green algae (Cyanobacteria) like Anabaena, Nostoc, Azolla, etc. In the process, nitrogen undergoes a set of changes, in which two nitrogen atoms get separated and combine with hydrogen to form ammonia (NH^{4+}).

(2) Nitrification- Nitrifying bacteria known as chemoautotrophs are responsible for carrying out the process of nitrification. The term nitrification refers to the conversion of ammonium to nitrate. First step is carried out by *Nitrosomonas sp.* whereas second step is carried out by *Nitrobacter sp.* Or *Nitrospira sp.* Both steps/reactions use NH_4^+ and NO_2^- as an energy source whereas CO_2 as a carbon source. This is a non-photosynthetic type of growth. NH_3 and NH_4^+ are both either assimilated by aquatic plants for growth or nitrified (oxidized) to NO_3^- (nitrate). Nitrate can also be used as a growth substrate. It is a two-step process:

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1. $NH_4^+ + 1.5\ O_2 = NO_2^- + 2H^+ + H_2O$
2. $NO_2^- + 0.5O_2 = NO_3^-$

These oxygen-driven reactions works best at pH 7-8 and at a temperature of 25-30 degree Celsius. However, under low dissolved oxygen conditions, it runs in reverse direction. It occurs in the hypolimnion under eutrophic (stagnant) conditions.

(3) Assimilation- Plants take in the nitrogen compounds which are available in the form of ammonia, nitrite ions, nitrate ions or ammonium ions and are used in the formation of the plant as well as animal proteins. By this way, it enters the food web when the primary consumers eat the plants.

(4) Ammonification- When plants or animals die, the nitrogen present in the organic matter is released back into the soil. The decomposers, namely bacteria or fungi present in the soil, convert the organic matter back into ammonium. This process of decomposition produces ammonia, which is further used for other biological processes.

(5) De-nitrification - By this process, NO_3^- in water is converted into atmospheric N_2, nitric oxide or nitrous oxide. This must occur under anaerobic conditions (anaerobic respiration). The process is carried out by bacteria like *Pseudomonas sp., Alkaligenes sp.* and *Bacillus sp.*

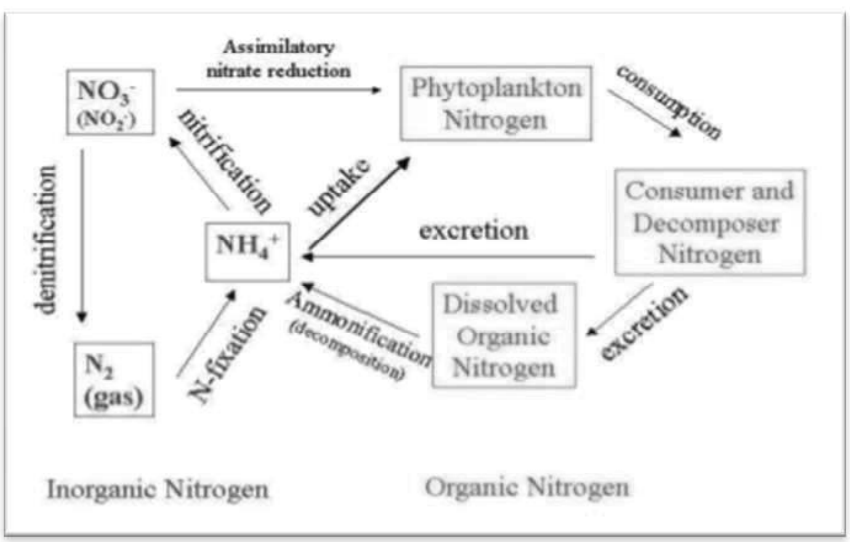

Fig. 2.19 *Nitrogen Cycle*

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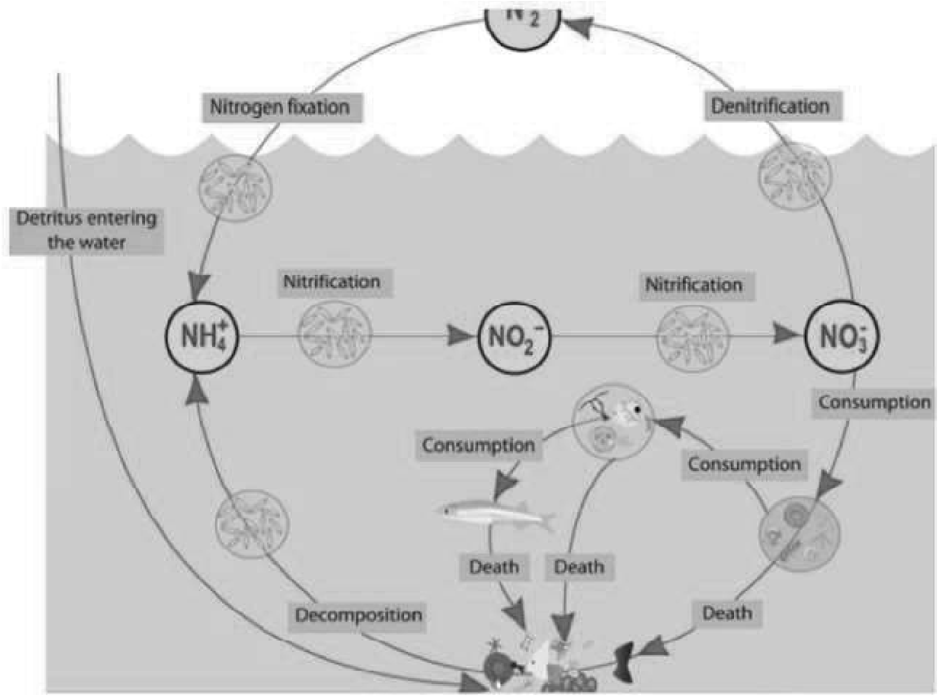

Fig. 2.20 *Nitrogen Cycle*

Figures 2.19 and 2.20 are depicting the Nitrogen cycle in fresh water system.

2.6.1 Phosphorous Cycle in Fresh-Water System

Phosphorous is an essential component of biomolecules like ADP and ATP, nucleic acids, phospholipids (membranes), apatite (bones and teeth), etc. In one of the study conducted by oceanographer ***Redfield*** in the 1950's, Phosphorous is considered to be the most limiting nutrient in the fresh-water system because the amount of Phosphorous available to organisms is much less than the amount required when compared to other elements. In freshwater, P (Phosphorous) is often 80,000 less concentrated than the amount required by phytoplankton.

Forms and Measurement of Phosphorous

Total **Phosphorous (P) = DIP + DOP + PP**

a. **DIP – (<5%) Dissolved Inorganic Phosphorus**-PO_4^{3-} polyphosphates

b. **DOP – Dissolved Organic Phosphorus** - Often associations of organic colloids. Alkaline phosphatase enzyme facilitates the release of Phosphorous from these organic compounds

c. **Particulate Phosphorus (PP)** Often largest percentage of P in lakes (>70%) – nucleic acids (decompose slowly), phosphate sugars, ATP (available more quickly, most P is in organic matter — living or dead organisms, some particulate Phosphorous is mineral Phosphorous. -

Sources of Phosphorous

a. **Rock Weathering**- It involves weathering of calcium phosphate minerals, especially apatite [$Ca_5(PO_4)_3OH$]. However, it is a slow process and happens over a period of time.

b. **Phosphorous** is mostly stored in marine deep ocean sediments.

Modes of Entry of Phosphorous to aquatic systems.

i. Precipitation – by dust in air

ii. Groundwater –Phosphorous adsorbs to soil particles.

iii. Surface runoff.

Steps of Phosphorous Cycle

Steps involved in the phosphorous cycle are as follows**:**

(1) Entry of Phosphorous into Aquatic System

Phosphorous can enter inside aquatic system via different modes as described in the above section.

(2) Absorption by Plants

The phosphate salts dissolved in water are absorbed by the plants. The aquatic plants absorb inorganic phosphorus from lower layers of water bodies. Since phosphate salts do not dissolve in water properly, they affect plant growth in aquatic ecosystems.

(3) Absorption by Animals

The animals absorb phosphorus from the plants or by consuming plant-eating animals.

(4) Return of Phosphorus Back to the Ecosystem

When the plants and animals die they are decomposed by microorganisms. During this process, the organic form of phosphorus is converted into the inorganic form, which is recycled back to water.

Water will end up in sediments or rocks, which will again release phosphorus by weathering. Thus, the phosphorus cycle starts all over again.

Decomposition and Excretion

i. Biota persist due to well-developed, efficient recycling of Phosphorous

ii. Phosphorous excreted by animals is rapidly taken up by algae as well as bacteria present in aquatic system.

iii. Decomposition helps in the liberation of usable Phosphorus

iv. Organic phosphorous $\rightarrow PO_4^{3-}$

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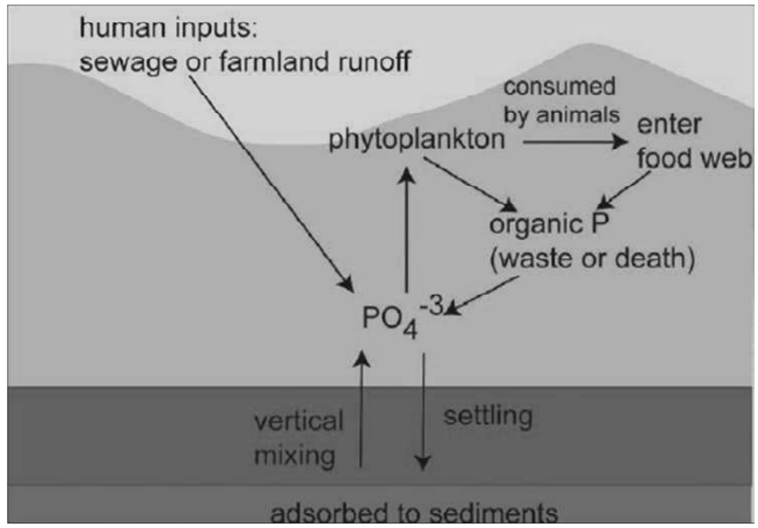

Fig. 2.21 *Phosphorous Cycle in Aquatic System*

Figure 2.21 illustrate the Phosphorous cycle in aquatic system.

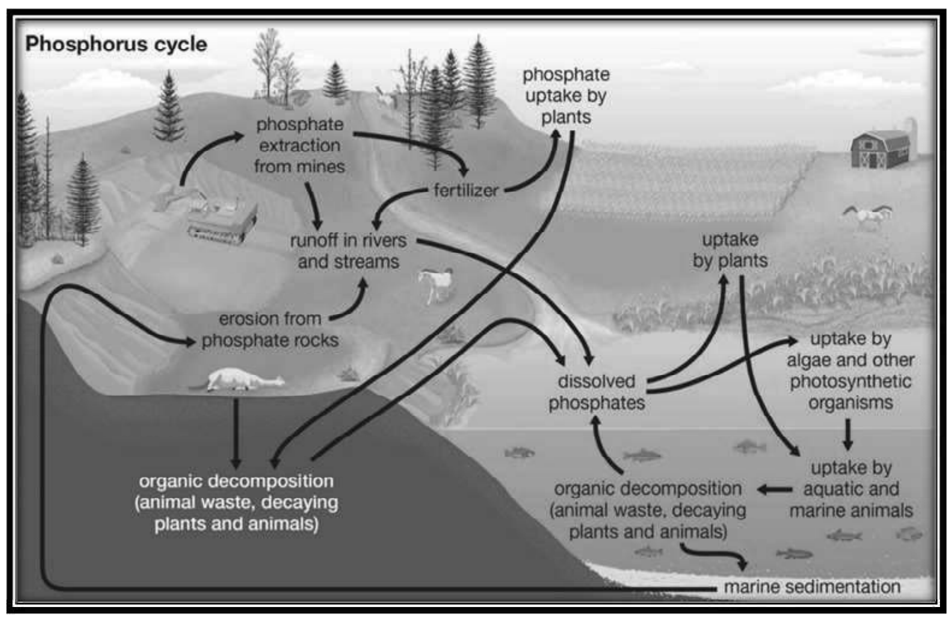

Fig. 2.22 *Phosphorous Cycle*

Figure 2.22 depicts the Phosphorous cycle.

2.6.2 Sulphur Cycle in Fresh Water System

Sulphur is a yellow, brittle, tasteless, odourless non-metal. It is one of the most abundant elements in nature and is present in almost all kinds of proteins. Sulphur is released into the atmosphere via:

- Burning of fossil fuels
- Volcanic activities
- Decomposition of organic molecules.

On land, sulphur is stored in underground rocks and minerals. It is released by:

- Precipitation
- Weathering of rocks
- Geothermal vents.

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There occurs a continuous loss of sulphur from terrestrial ecosystems as some of it drains into lakes as well as streams and eventually into the ocean as runoff. There are several natural sources like volcanic eruptions, evaporation of water, and breakdown of organic matter in swamps, that release sulphur directly into the atmosphere. This sulphur falls on earth with rainfall. Figure 2.23 is depicting the sulphur cycle.

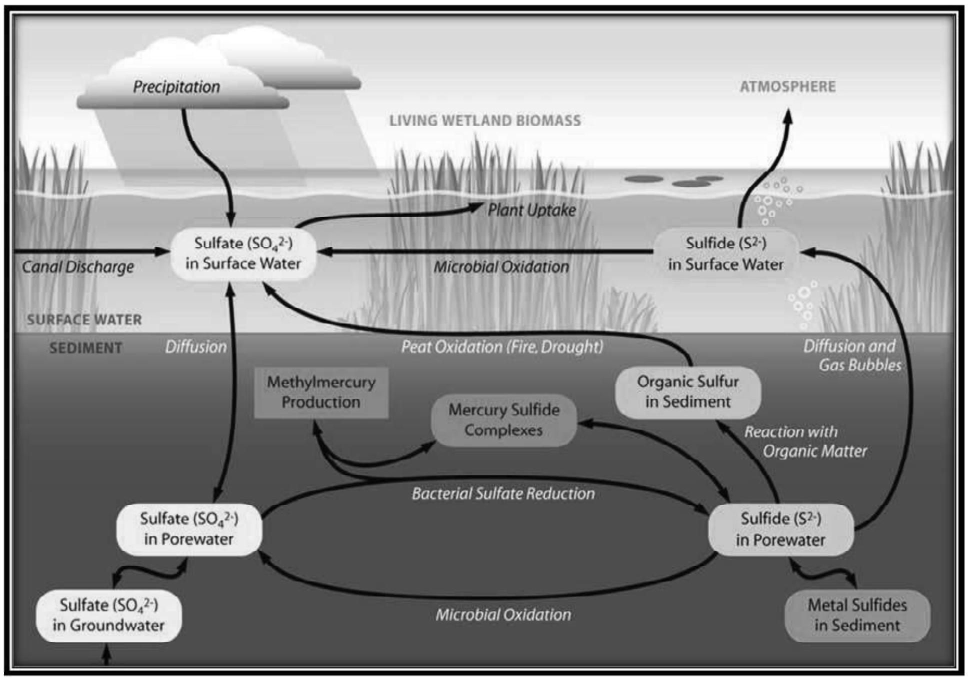

Fig. 2.23 *Sulphur Cycle*

Sulphur Cycle

The sulphur cycle is described below:

- The sulphur is released by geochemical and meteorological processes like the weathering of rocks.
- When the released Sulphur comes in contact with air, it gets converted into sulphates (SO_4).
- These Sulphates are taken up by plants as well as microorganisms and are converted into organic forms.
- Animals acquire these organic forms of sulphur from their foods.
- Death and decomposition of the animals leads to release of some of the sulphur while some enter the tissues of microbes.

Steps of Sulphur Cycle

Sulphur cycling, one of the active biological processes in aquatic sediments, is catalysed by Sulphate-Reducing Prokaryotes (SRPs) and Sulphur-Oxidizing Prokaryotes (SOPs).

Following are the important steps of the sulphur cycle

(1) Decomposition of Organic Compounds

Sulphate is one of the major ion in lake waters. Under anaerobic conditions, in which bacteria persist in the oxidation of biological material, hydrogen sulphide is produced. Further, hydrogen sulphide reacts when anoxic situations happen in the deep waters just above the sediments, and the water is sufficiently acidic to precipitate the iron present.

(2) Oxidation of Hydrogen Sulphide to Elemental Sulphur

Hydrogen sulphide oxidises to produce elemental sulphur. Certain photosynthetic bacteria from the families *Chlorobiaceae* and *Chromatiaceae* initiate the oxidation process.

(3) Oxidation of Elemental Sulphur

Elemental sulphur is converted into sulphates by *chemolithotrophic* bacteria.

(4) Reduction of Sulphates

Sulphates are reduced to hydrogen sulphide by *Desulfovibrio desulfuricans.* This occurs in two steps:

- Firstly, the sulphates are converted to sulphites utilizing ATP.
- Secondly, the reduction of sulphite to hydrogen sulphide.

Once in the aquatic system, some of the sulphur cycles via freshwater communities as it moves through food chains, some re-enters the atmosphere, and some is lost to the freshwater depths where it combines with iron to form ferrous sulphide (FeS). Sulphur re-enters into the atmosphere as:

(a) Anaerobic Respiration by sulphate-reducing bacteria causes the release of hydrogen sulphide (H_2S) gas especially from marshes, tidal flats, and similar environments in which anaerobic microorganisms thrive.

(b) Volcanic Activity releases additional but much smaller amounts of sulphur gas into the atmosphere.

Anthropogenic activities have contributed largely to the amount of sulphur present in freshwater system. Rapid burning of fossil fuels due to industrialization as well as over use of vehicles has contributed much to the acidification of freshwater ecosystems. The major contributors to freshwater acidification are sulphur oxides and nitrogen oxides. Increases in concentration of sulphate in runoff (due to increased acidity inputs) is associated with an increase in base cation run-off as well as bicarbonate decrease, producing the acidifying effect as observed in freshwater ecosystems. In a natural state, most of the nitrogen entered into freshwater ecosystems will be used by vegetation. However, when present in excess amounts, all of the nitrogen is unable to be utilized by vegetation, and excess nitrogen is found as nitrate in the water's runoff. Nitrate as well as sulphate contribute to the acidification of the aquatic system in the same way. Figure 2.24 is depicting the sulphur cycle in freshwater system.

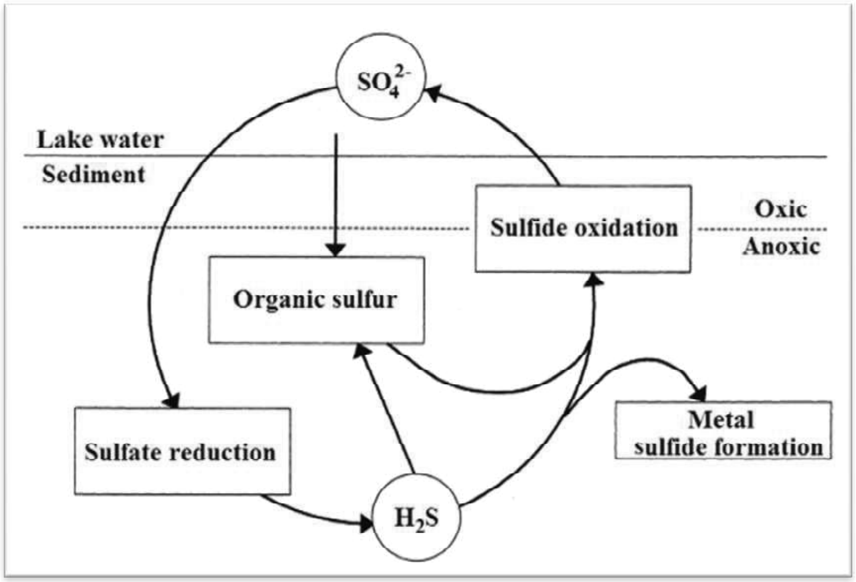

Fig. 2.24 *Sulphur Cycle in Freshwater System*

Check Your Progress

8. Define the term biogeochemical cycle.
9. What do you understand by the term nitrification?
10. How silica does enters into the aquatic environments?
11. What is Nitrogen fixation?
12. What happens in the process de-nitrification?
13. How the absorption of phosphorous is carried out by plants.
14. How the Sulphur is released into the atmosphere.

2.7 INORGANIC CARBON IN FRESHWATER SYSTEM

Inorganic carbon is present in the atmosphere, chiefly in the form of carbon dioxide (CO_2) having a concentration of around 350 ppm. This concentration of carbon dioxide in the atmosphere is continuously increasing since the industrial revolution, leading to the greenhouse effect. When carbon dioxide is dissolved in water, it can exist in a variety of forms, depending on the pH of the aquatic system. The different forms in which carbon dioxide exist in aquatic system are: carbon dioxide, carbonic acid, bicarbonate and carbonate. The percentage of all these constituents is also dependent on the pH of the body of water. The sum total of the concentrations of all these forms together is referred to as the inorganic carbon concentration and is denoted by ΣCO_2. Under most situations in aquatic systems, carbon dioxide is quickly converted to carbonic acid so more or less they are considered as the same. The chemical conversions among carbon dioxide and carbonic acid is referred to as the **bicarbonate equilibrium**. The bicarbonate equilibrium can be denoted as:

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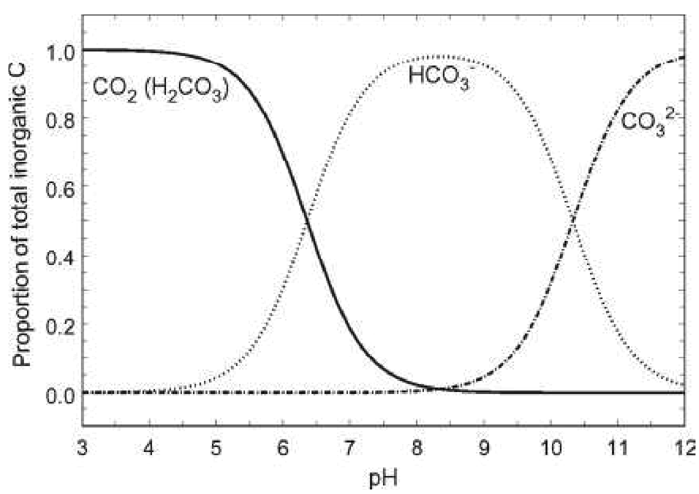
$CO_2 + H_2O \Leftrightarrow H_2CO_3 \Leftrightarrow H^+ + HCO_3 \Leftrightarrow 2H^+ + CO_3^-$

Where: CO_2 - Carbon dioxide, H_2O- Water molecule, H_2CO_3- Carbonic acid, HCO_3^-- Bicarbonate ion.

The 'Ô!' symbol indicates an equilibrium reaction. Addition or removal of chemicals at any part of the reaction can force the reaction. For instance, if acid (H^+) is added to a bicarbonate solution, the equilibrium is weighted too heavily to the right-hand side of the equation, pH will decrease (solution will become more acidic) so the bicarbonate will convert spontaneously to carbonic acid or carbon dioxide. This can be easily explained by adding an acid like vinegar to a solution of the sodium salt of bicarbonate (baking soda). Adding vinegar (the acid) will cause production of carbon dioxide as the equilibrium is re-established. As the CO_2 gas has a limited solubility in acidic water, it will bubble out. Thus, with change in pH of the aquatic system there will be a corresponding change in the relative concentration of bicarbonate, carbonate as well as carbonic acid.



Graph shows the varying concentration of total inorganic carbon with pH.

The above plot can be used to estimate the concentrations of each of the forms of inorganic carbon when the pH is known. Such data are valuable as CO_2 is the form of inorganic carbon which is required for carrying out the process of photosynthesis. Many photosynthetic organisms present in the aquatic system can convert bicarbonate to CO_2, however CO_2 is still the most convenient used form. Thus, knowing the alkalinity and pH of a solution allows a researcher to estimate the amount of inorganic carbon that is directly available for carrying out the process of photosynthesis in freshwater ecosystem. Further, increased atmospheric pressure lets in increased amounts of CO_2 to be dissolved in solution. For instance, a carbonated drink (beer, champagne, soda, etc.) which is stored under pressure lose CO_2 when opened. Additionally, freshwater reservoir's pH values are altered by acid rain, surface run off (nutrient rich runoff from surface), and other anthropogenic pollutants. It is often difficult to quantify the effects of pCO2 levels in freshwater system due to the various sources of carbon dioxide

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received by the freshwater ecosystems. The CO_2 absorbed by the freshwater ecosystem depends upon a lot of factors like watershed, agriculture, land-use, watershed, lake-size, precipitation, soil-type, rock type, etc. Anthropogenic activities have greatly contributed to the increase in PCO2 level in freshwater ecosystems. As the vegetation near freshwater ecosystems keeps on growing and thriving well due to the excess PCO2 feeding these plants, the carbon available at death and decomposition increases. Then, natural processes like precipitation, weathering as well as surface runoff will wash this soil into the nearby water. When the pCO2 from the decomposing vegetation reacts with the water present in the aquatic system, it forms carbonic acid, which further contributes to a lower pH level. Figure 2.25 is depicting the Carbon-dioxide cycle in freshwater system.

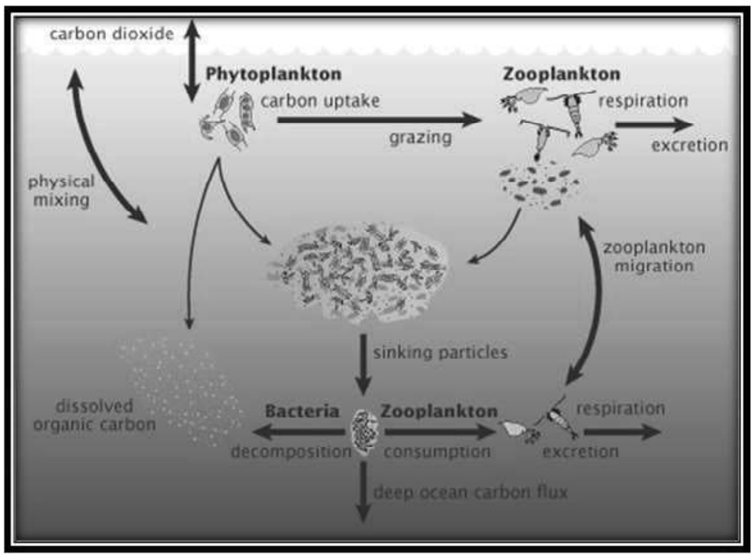

Fig. 2.25 *Carbon-Dioxide Cycle in Freshwater System*

Factors Contributing To Acidification of Fresh-Water System

As seen in the above section, a change in pH contributes of the aquatic system brings about a corresponding change in the relative concentration of bicarbonate, carbonate as well as carbonic acid. This section lists down the factors responsible for acidification of the freshwater aquatic system:

(1) Sulphur Oxides and Nitrogen Oxides (Anthropogenic activities)

Rapid burning of fossil fuels due to industrialization as well as over use of vehicles has contributed much to the acidification of freshwater ecosystems. The major contributors to freshwater acidification are sulphur oxides and nitrogen oxides. Increases in concentration of sulphate in runoff (due to increased acidity inputs) is associated with an increase in base cation run-off as well as bicarbonate decrease, producing the acidifying effect as observed in freshwater ecosystems. In a natural state, most of the nitrogen entered into freshwater ecosystems will be used by vegetation. However, when present in excess amounts, all of the nitrogen is unable to be utilized by vegetation, and excess nitrogen is found as nitrate in the water's runoff. Nitrate as well as sulphate contribute to the acidification of the aquatic system in the same way. Figure 2.26 is depicting the anthropogenic source of acidification of freshwater system.

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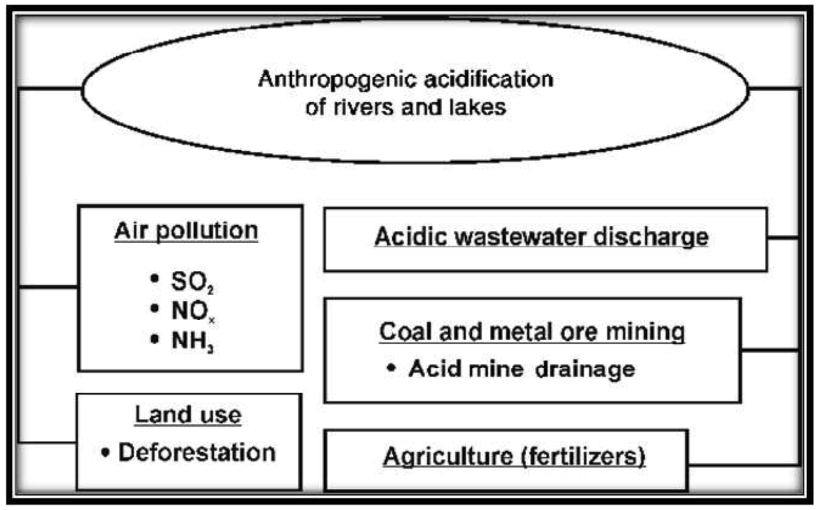

Fig. 2.26 *Anthropogenic Source of Acidification of Freshwater System*

Source of Information- Encyclopedia of Environmental Management Rivers and Lakes: Acidification Rivers and Lakes: Acidification

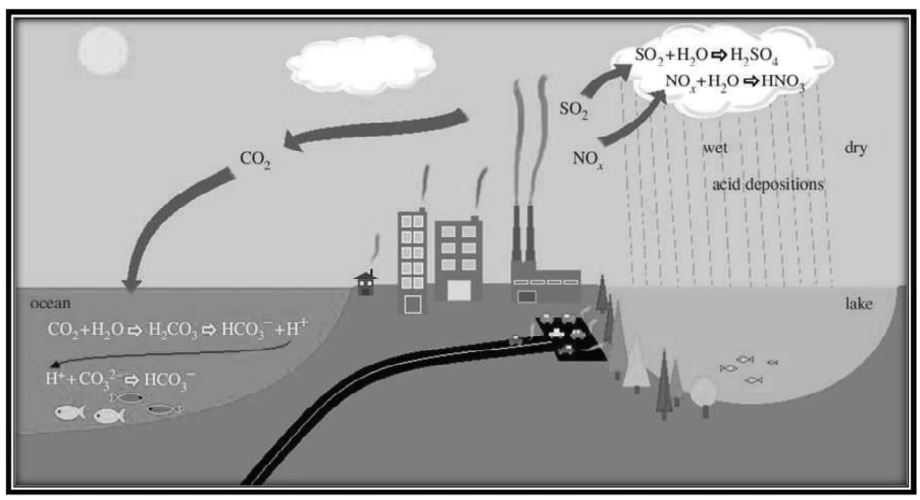

Fig. 2.27 *Acidification of Lakes*

(2) Buffering Capacity of Freshwater Ecosystem:

In addition to sulphur oxides and nitrogen oxides, low buffering capacities of freshwater ecosystems can also lead to freshwater acidity. The equilibrium reaction of inorganic carbon also explains the acid neutralizing or buffering capability of bicarbonate as well as carbonate. As acid is added to the solution, Protons react with the carbonate, so pH changes slightly when compared to the concentration of H^+ added to solution. Aquatic systems having a significant amount of dissolved bicarbonate (limestone watersheds) are able to resist the effects of acid precipitation. However, an opposite response ensues on addition of base (OH^-) to the system. The OH^- ions associate with the H^+ ions so the equilibrium balances by moving toward the bicarbonate side.

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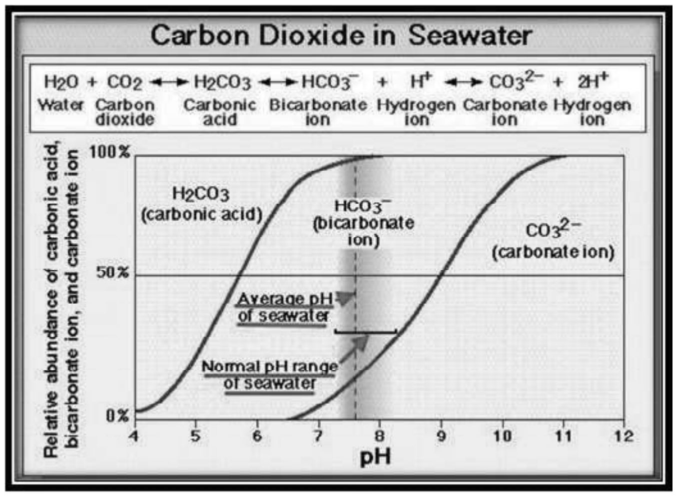

Graph depicts the resistance of sea water against pH change

Freshwater uptakes carbon dioxide from the atmosphere in the same mechanism as seawater, however, freshwater alkalinity is much lower as compared to seawater, due to the absence of a salt-buffer. Due to the lack of salt-buffer, pH changes in freshwater tend to be much greater than ocean water, due to newly released H^+ ions not being buffered by as many bicarbonate (HCO_3^-) ions as ocean water. Hence, the biotic communities residing in freshwater exhibits a higher evolutionary pH tolerance as compared to seawater biota. The acid and base neutralizing capacity of bicarbonate and the predominance of bicarbonate ions in many aquatic systems have led to using alkalinity and acidity titrations to estimate ÓCO_2. Table 2.2 depicts the difference in the composition of sea vs fresh water.

***Table 2.2** Difference in the Composition of Sea vs Fresh Water*

River Water vs. Ocean Water Composition

Dissolved Ion	River Water	Ocean Water
Bicarbonate (HCO_3^-/CO_3^{--})	48.7%	0.4%
Calcium (Ca^{++})	12.4%	1.2%
Silica (SiO^{++})	10.8%	----
Sulfate (SO_4^{--})	9.3%	7.7%
Chloride (Cl^-)	6.5%	55.0%
Sodium (Na^+)	5.2%	30.6%
Magnesium (Mg^{++})	3.4%	3.7%
Potassium (K^+)	1.9%	1.1%
Nitrate (NO_3^-)	0.8%	----
(Fe, Al) $2O_3$	0.8%	----

(3) Natural Factors Responsible for Acidification of Fresh-Water Bodies

A lot of geological, geo-chemical, climatic as well as biological factors are responsible for the acidification of freshwater bodies. Figure 2.28 depicts natural sources of acidification of freshwater bodies.

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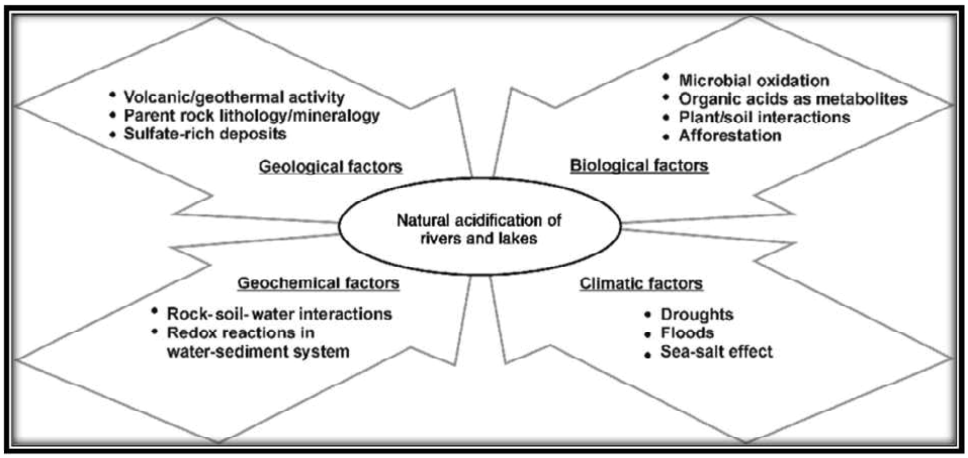

Fig. 2.28 *Natural Sources of Acidification of Freshwater Bodies*

Source of information: Encyclopedia of Environmental Management Rivers and Lakes, Acidification Rivers and Lakes, Acidification.

Harmful Effects of Acidification on Aquatic Ecosystems

Biodiversity is affected by increase in the acidification of the freshwater ecosystem. For instance: a drop in pH value to 6 would considerably affect the population of both snail as well as crustacean's species within freshwater ecosystem. Further, in acidic freshwater reservoirs, a tremendous increase in the development of mosses and algae is observed specifically of the moss Sphagnum. Moss Sphagnum has a very high capacity to exchange H^+ for basic cations within freshwater. The thick layer of Sphagnum is limiting the exchange between surface water and sediment, which additionally contributes to decrease in nutrient cycling in the ecosystem. Figure 2.29 depicts the overabundance of sphagnum in a pond system.

Fig. 2.29 *Overabundance of Sphagnum in a Pond System*

2.8 PRODUCTIVITY OF FRESHWATER ECOSYSTEM

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Central to all biological activity within inland aquatic ecosystems is biological productivity or aquatic production. In ecology, the term productivity refers to the rate of generation of biomass (It is referred to as the weight of all living material in a unit area at a given instant in time) in an ecosystem, usually expressed in units of mass per volume (unit surface) per unit of time, such as grams per square metre per day (g m^{-2} d^{-1}). The unit of mass can relate to dry matter or to the mass of generated carbon. This involves two main processes:

(1) Primary Production – In ecology, primary production refers to the synthesis of organic compounds from atmospheric or aqueous carbon dioxide. It chiefly occurs via the process of photosynthesis, which utilizes light as its source of energy, however, it also occurs via chemosynthesis, which uses the oxidation or reduction of inorganic chemical compounds as its source of energy. In short, the productivity of autotrophs, such as plants, is known as primary productivity. Estimates of primary productivity by photosynthesis can be obtained directly by following changes in oxygen production or rates of inorganic carbon assimilation. Further, primary productivity can be studied under two categories:-

  (a) Gross Primary Production—Gross primary production refers to the total amount of energy fixed by photosynthesis.

  (b) Net Primary Production— Net primary production is the rate at which all the autotrophs in an ecosystem produce net useful chemical energy. As noted, it is equal to the difference between the rate at which the plants in an ecosystem produce useful chemical energy (GPP) and the rate at which they use some of that energy during respiration. This energy (Net primary production) is available for secondary production.

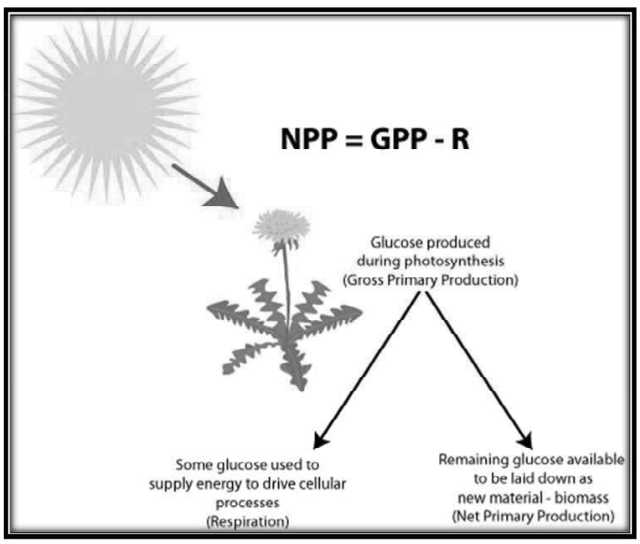

***Fig. 2.30** Difference between Gross Primary Production and Net Primary Production*

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Figure 2.30 is depicting the difference between Gross primary productions. and Net Primary Production.

(2) Secondary Production- The productivity of autotrophs, such as plants, is called primary productivity, while the productivity of heterotrophs, such as animals, is called secondary productivity. The ratio of productivity to biomass (P/B ratio) estimates the turnover rates of energy flow relative to biomass; P/B values generally decrease with increasing trophic level. Figure 2.31 is depicting the net energy available for growth at consumer level.

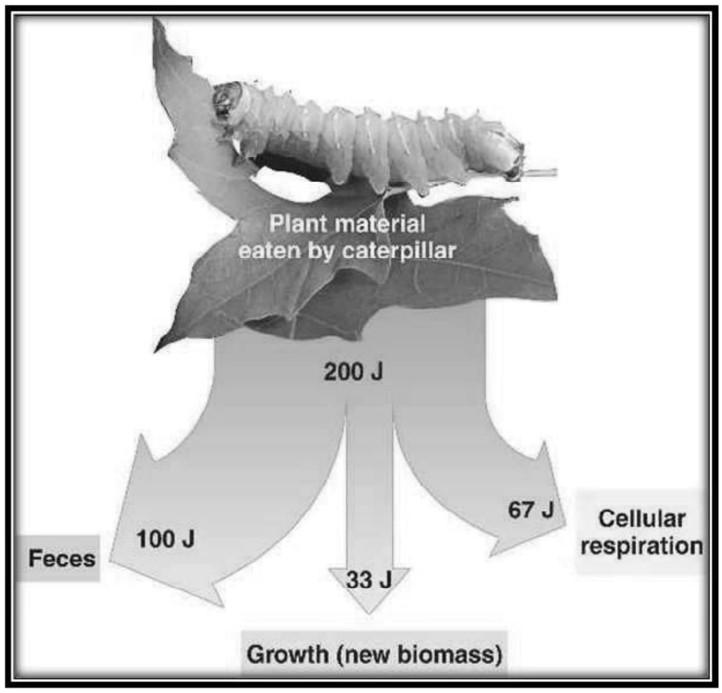

Fig. 2.31 *Net Energy Available For Growth*

2.8.1 Factors Affecting Productivity of Freshwater Ecosystem

Factors affecting the rate of biological productivity have been a matter of fundamental interest in inland waters as it affects the human population. For instance: A reduction in the fish population (due to decreased levels of secondary production) can lead to an inadequate return, which can in turn affect the fish supply to human populations which further can disturb the physical, social and commercial well-being of local population dependent upon fish production. This section discuss in detail about the factors affecting the productivity of freshwater ecosystem:

1. Thermal Property of Fresh-Water System

Temperature is a physical quantity that expresses hotness and coldness. It is the manifestation of thermal energy, present in all matter, which is the source of the occurrence of heat, a flow of energy, when a body is in contact with another that is colder or hotter. Temperature of water bodies varies with place and time due to changing atmospheric conditions. Temperature of water ranges anywhere from 0 to 100 degree Celsius. It is measured using thermometers. The temperature keeps on decreasing gradually from the surface to the bottom of the water body. Temperature fluctuations produces typical patterns of circulation as well as stratification within the water bodies. On the basis of tolerance to temperature, organisms can be classified as stenothermal and eurythermal organisms. Eurythermal organisms are those which can withstand a wide range of temperature, whereas stenothermal organisms are those that only survive in a narrow temperature range. Therefore, even a small change in temperature can have widespread effects especially stenothermal organisms.

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2. Transparency of the Fresh-Water System

The material that increases the turbidity of water includes slit, tiny organic matter, inorganic material, clay, plankton, dissolved matter as well as other microscopic organism. Higher turbidity makes the water cloudy or opaque. Turbidity of water directly influences the penetration of light. It limits the penetration of light in the aquatic bodies. Productivity of the fresh water system depends upon the penetration of the light. For instance: Large shallow lakes tend to be more productive when compared to lakes with deep water as more light reaches the lake bed. In larger rivers, the canopy is open which allows the algal production.

3. Current

Current also a significant role in estimating the distribution of salts, vital gases as well as minute organisms. It acts as an essential limiting factor for the lotic systems particularly for streams.

4. Trophic Conditions of the Fresh-Water System

Trophic conditions indicate the biological productivity of the fresh-water system. Productivity of the freshwater system varies according to the varying concentration of Chlorophyll (Chl), Phosphorus (P) and microorganisms present, etc. In this case, the fresh-water is divided into classes namely:

1. Oligotrophic- The biological productivity of oligotrophic fresh-water system is very low due to its low nutrient content. The water of such system is clear and highly transparent.
2. Mesotrophic- The term 'Meso' means medium. Mesotrophic fresh-water system contains moderate amount of nutrients like phosphorus and nitrogen which promotes the growth of planktons. The water of such fresh-water system is clear, with aquatic plants submerged at the bottom and some algae blooms at the end of summer.
3. Eutrophic- The word eutrophic is derived from the Greek '*eutrophos*' which means rich in nutrients. Eutrophic fresh-water system are those system which exhibits very high biological productivity. High nutrient content of eutrophic fresh-water system promotes growth of aquatic organisms.
4. Hypereutrophic- Hypereurotrophic fresh-water system are excessively rich in nutrients leading to algal blooms. Algal blooms lead to reduced dissolved oxygen levels resulting in a low-depth death zone beneath the surface of such a reservoir, which reduces the density of the organism.

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5. Dystrophic- Dystrophic fresh-water system are rich in humic substances as well as organic acids, so the water is usually brown or tea-colored. Additionally, the amount of calcium, phosphorus and nitrogen is very low in such system. The bottom of such fresh water system contains sufficient amount of organic and dehydrated matter and less amount of electrolyte. In addition, deep water in most cases does not contain dissolved oxygen.

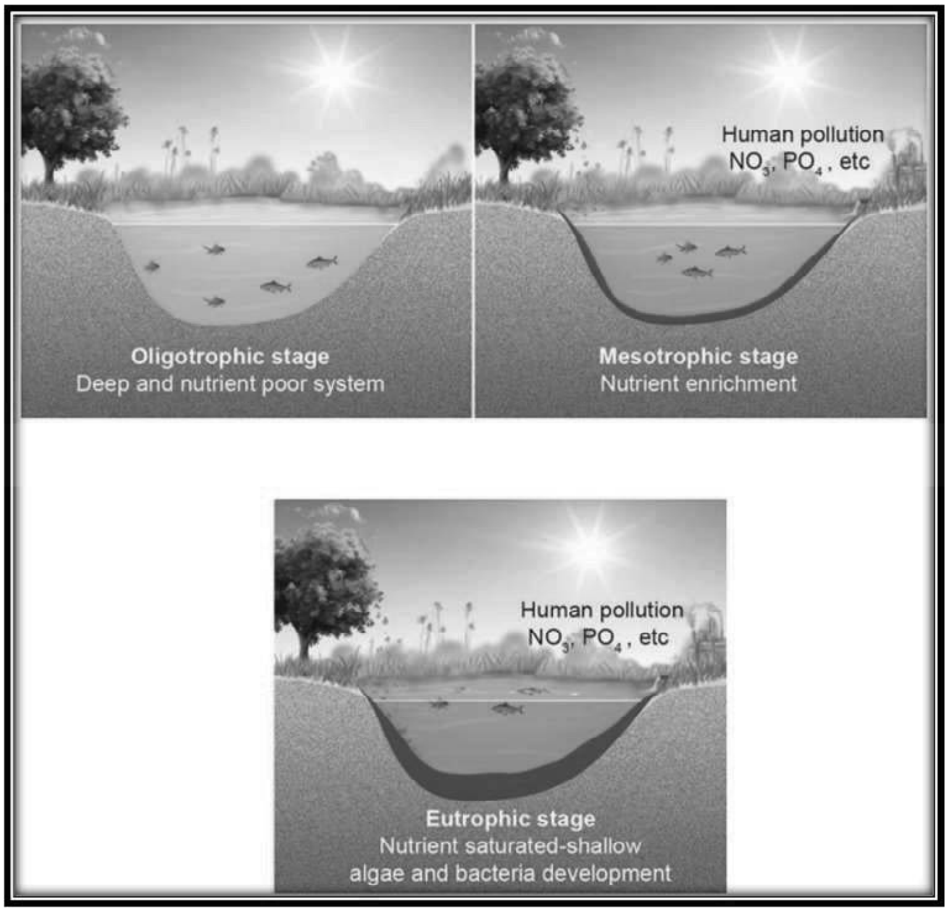

Fig. 2.32 *Productivity of an Oligotrophic, Mesotrophic and Eutrophic Freshwater System*

Figure 2.32 depicts the productivity of an oligotrophic, mesotrophic and eutrophic freshwater system. Further, fresh water system receives excess salts from the discharge due to contamination by chemicals, hazardous materials and other foreign particles leading to excessive primary production. Elevated levels of primary production due to the input of excess plant nutrients, principally phosphates and nitrates, into inland waters following urban waste discharge, surface run-off, agricultural can also be harmful. Over a period of time, anthropogenic activities like use of excessive fertilizers in agricultural field, disposal of nutrient rich waste into water bodies etc. has increased the nutrient content of freshwater bodies ultimately leading to the deterioration of water quality and making it unfit for human consumption.

5. Concentration of Hydronium Ions in Fresh-Water System

If the pH of water is too high or too low, the aquatic organisms living within the water bodies will die. The pH can alter the solubility as well as toxicity of chemicals and heavy metals in the water. The majority of aquatic creatures prefer a pH range of 6.5-9.0, though some can live in water with pH levels outside of this range. As pH levels move away from this range (up or down) it can stress animal systems and reduce hatching and survival rates.

6. Salinity of the Freshwater

Anthropogenic activities like agriculture or salt mining or discharge of pollutants in fresh water bodies along with climatic aridification and rising sea levels, are increasing salt concentrations in inland freshwaters as well as coastal habitats, which produces severe negative economic and biological effects. At levels above or below the isosmotic point of organism internal fluids, salinity can disrupt metabolism and water balance. Hence, aquatic organisms have evolved different mechanisms of intra- and extracellular osmoregulation to control osmotic and dehydration stress in the face of salinity changes in the external environment. A change in salinity of the freshwater bodies may adversely affects the growth, survival and reproductive capabilities of the organisms living in it.

2.8.2 Biotic Communities Found in Freshwater Depending Upon Its Productivity

The number and variety of biotic communities present in freshwater system depends upon its productivity. This productivity in turn depends on the availability of energy (usually solar) and raw materials (nutrients, minerals) within the ecosystem. Obviously, the available energy is continuously varying with daily and seasonal cycles, and the raw materials are continuously cycling (water cycle, carbon cycle, nitrogen cycle, phosphorus cycle, sulfur cycle, iron cycle, manganese cycle, etc.) through and within the ecosystem. These fluctuations also help to determine the shorter-term productivity of the system.

The process of photosynthesis is the basis of life in an aquatic ecosystem. In simple terms, it is referred to as the process by which green plants and some other organisms use sunlight to synthesize foods from carbon dioxide and water. Photosynthesis in plants generally involves the green pigment chlorophyll and generates oxygen as a by-product or it can also be said that this process is the conversion of solar energy and nutrients to living biomass in the form of green plants. In an aquatic ecosystem, these green plants can take several forms and are typically grouped as either algae (microscopic plants) or macrophytes (large plants, often rooted). Collectively, all these plants form the base of the freshwater food web. Their conversion, via the process of photosynthesis, of inorganic nutrients and minerals to living (organic) matter is referred to as **primary production**. Without primary production, there would be no new biomass produced within the ecosystem to support other life forms or secondary production. Figure depicts the producers and different levels of consumers in a fresh-water system.

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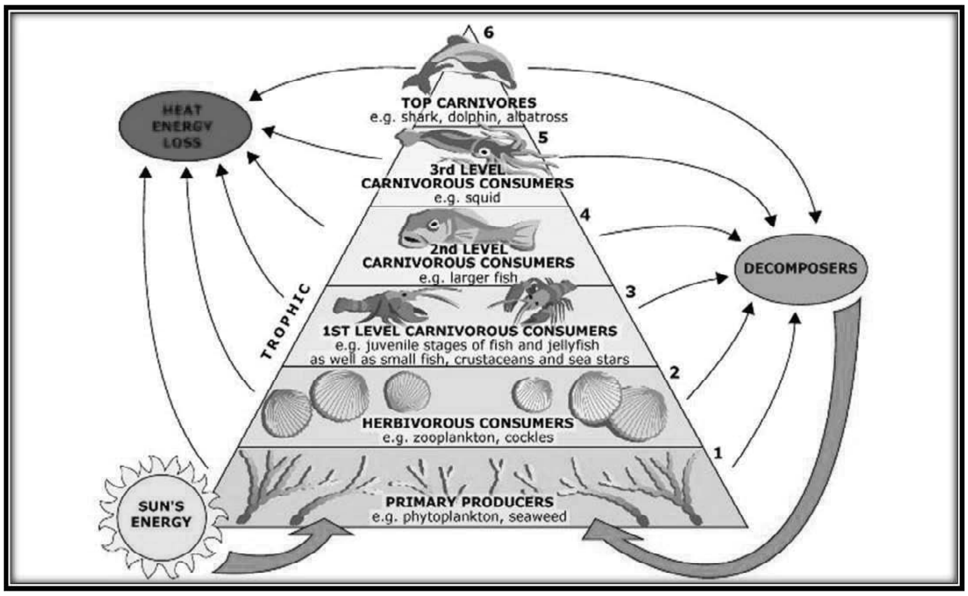

Fig. 2.33 *Producers and Different Levels of Consumers in a Fresh-Water System*

(1) Primary Producers

Phytoplankton are small microscopic, unicellular and photosynthetic organisms which freely float in water bodies. Phytoplankton composed of both eukaryotic as well as prokaryotic species which colonizes upper euphotic part of the water column ranging from freshwater to ocean conditions. They also exhibit amazing adaptation to remain in floating condition. The range of the Phytoplankton cells can vary in size from about 1 ìm to 1 mm. Like terrestrial plants, these tiny primary producers need sunlight, nutrients as well as carbon dioxide for their growth and multiplication. Phytoplankton cells contains chlorophyll which helps them to synthesize food in the presence of sunlight. Therefore, they not only help in maintaining the carbon dioxide level but also to alleviate global warming to some extent. Physical process like wind and current play substantial part in their distribution particularly in estuarine and marine conditions. Phytoplankton act as primary link in energy pathway to higher trophic level via several food chains. Phytoplankton supports nearly half of global primary production which directly or indirectly supports almost all marine life. Phytoplankton are a chief food source for diverse range of organisms like zooplanktons, larvae, juveniles of fishes as well as some invertebrates. The annual cycle of the phytoplankton remains predictable throughout the year, however, occasionally some species may develop exponentially leading to the formation of algal blooms.

Primary producers in Lentic water (Standing water)

Phytoplankton and periphyton are the chief primary producers in lentic water system. Phytoplankton are seen drifting in the water column of the pelagic zone. However, several phytoplankton have a higher density and sink to the benthic region. Periphytons remains attached to the substrate covering almost the entire benthic surfaces. Phytoplankton as well as periphyton serves as important food source and chief oxygen producers in the lentic system. Further, Plants, or

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macrophytes, are found in both the benthic and pelagic zones and can be categorized according to their way of growth

- **Emergent macrophytes** - Emergent macrophytes are rooted in the substrate, however their leaves and flowers extends into the air. They are present near the shoreline.
- **Floating-leaved macrophytes** - Floating-leaved macrophytes are rooted in the substrate but with floating leaves.
- **Submerged macrophytes** - Submerged macrophytes are not rooted in the substrate and floating beneath the surface.
- **Free-floating macrophytes** - Free-floating macrophytes are not rooted in the substrate and keeps on floating at the surface. They can be present in anywhere on the surface of lentic water.

Lentic systems gain most of their energy from photosynthesis performed by aquatic plants and algae.

(a) Primary Producers in Lotic system (Flowing Water)

Algae, comprised of phytoplankton and periphyton, are the major primary producers in most streams and rivers (Giller and Malmqvist 1998). Phytoplankton float freely in the water column however they are unable to maintain high populations in fast flowing streams. Phytoplankton population can rise steadily in slow moving rivers and backwaters (Allan 1995). Periphyton are typically filamentous in structure and remain attached to the objects to avoid being washed away by fast river/ stream current. In slow moving rivers/streams, periphyton may form a gelatinous, unanchored floating mat (Cushing and Allan 2001). Like phytoplankton and periphyton, plants also show limited adaptations to fast current and thus thrive only in slow moving waters. Primitive plants, like mosses and liverworts attach themselves to solid objects. Other plants like duckweed or water hyacinth floats freely at the water's surface. Rooted plants usually occur in areas of slackened current where fine-grained soils are found (Brown 1987; Cushing and Allan 2001). These rooted plants are flexible, with elongated leaves that offer minimal resistance to current (Angelier 2003). Phytoplanktons, periphyton as well as plants are essential to lotic systems and serve as food source, sources of energy, microhabitats for several animals, etc.

(b) Primary Producers in wetlands

Algae are chief part of a wetland ecosystem. Algae supply food for animals like small fish, insects and invertebrates. There are four main types of hydrophytes (plants that only live in or on water) in a wetland System. Submerged, floating, emergent shrubs and various amphibious trees.

- **Submerged water plants** - Submerged water plants are not rooted in the substrate and floating beneath the surface i.e. they are completely submerged in water.
- **Emergent water plants** - Emergent water plants are rooted in the substrate, however their leaves and flowers extends into the air. They are present near the shoreline.

- **Floating-leaved water plants -** Floating-leaved water plants are rooted in the substrate but with floating leaves. Their roots can easily suck nutrients.

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The Surrounding Plants as well as shrubs make up the swamp area that surrounds the wetland, usually in soils with a high saturated water level. These plants are adapted to wet conditions and hence can sustain life with a fair amount of water in their Cells.

Each group of primary producer's species is adapted to certain conditions of availability of nutrient, temperature, input of solar energy, water current as well as other environmental factors. Thus, some species will flourish in certain types of aquatic system, or at certain times of year, or under certain special conditions. If factors are ideal for a particular species, it will thrive well and flourish in that condition and other algal species in the lake will be less abundant. If conditions change significantly, other species better adapted to the new conditions may outcompete the original species and begin to dominate within the phytoplankton. For example, *Dinobryon* sp. are characteristically found in Boreal Shield lakes, where nutrient concentration especially that of phosphorous is low. These species can thrive well in the cold, clear water of these lakes, but the overall biomass of the community will be low. Contrarily, cyanophytes, such as *Anabaena* sp. are mostly adapted to warmer, nutrient-rich water, found in many prairie lakes.

(2) Zooplankton and Invertebrates

In general, where there is more algal growth (i.e., greater primary productivity), there will be more food available for next trophic level.

(a) Zooplankton and Invertebrates in Lentic Water

Zooplankters are microscopic, unicellular or multicellular forms with size ranging from a few microns to a millimetre or even more. Apart from size variations, zooplankters exhibit differences in morphological features as well as taxonomic positions consisting of representatives from almost every taxon of the animal kingdom. They are diverse, gentle and beautiful groupings of animals that drift in the aquatic bodies and adds substantially to the faunal biodiversity of aquatic bodies. They play a significant role in the marine food web. They help in transferring organic energy obtained from unicellular algae to higher trophic levels like pelagic stocks. They act as food source for larval as well as juvenile fish, hence their reproductive cycles, growth as well as survival rates are essential factors influencing fishery. Zooplankton have the ability to switch from laying regular eggs to resting eggs when there is a lack of food, temperatures fall below 2 °C, or if predator abundance is high. The invertebrates that inhabit the benthic zone are numerically dominated by small species and are species rich compared to the zooplankton of the open water. Invertebrate commonly found in the lentic water system include Crustaceans (for example crabs, crayfish and shrimp), molluscs (for example clams and snails) as well as numerous types of insects. All these organisms usually inhabits the areas of macrophytic growth having favourable conditions for their growth and survival like presence of food, optimal temperature as well oxygen. However, some invertebrates are also found in the cold, dark, and oxygen poor profundal zone. Zooplankton exhibits diverse food habits.

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(1) Protozoa: They feed upon minute algae and bacteria. Utilisation of dissolved substances has been demonstrated in certain protozoa.

(2) Metazoan – In 1929, Neumann considered the relation of zooplankton as seston feeders into the 4 types namely:

   a. Grasping type: They touch and secure seston with the help of pseudopodia like Rhizopoda
   b. Filtration type: It involves filtering of seston from water as animal moves.
   c. Sedimentation type: It involves capturing of seston via inducing water currents
   d. Predatory type: They capture other organisms

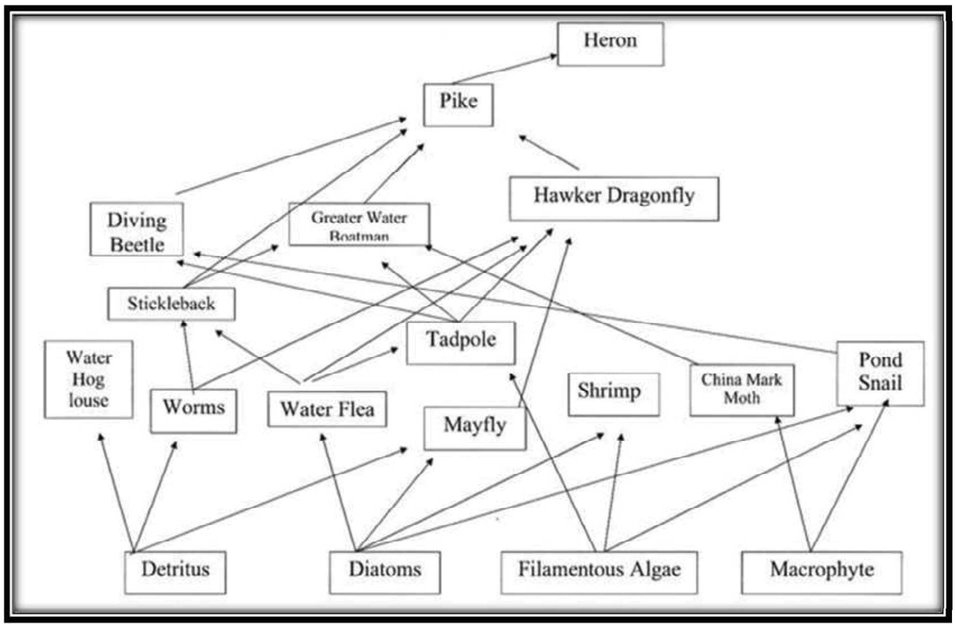

Fig.2.34 *Food-Web in a Pond Ecosystem*

Figure 2.34 depicting the food-web in a pond ecosystem

(b) Zooplankton and Invertebrates in Lotic water

Approximately, 90% of invertebrates in lotic systems comprises of insects. Most commonly found insects in the lotic system include mollusks such as snails, limpets, clams, mussels, as well as crustaceans like crayfish and crabs. They are present at places like surfaces of stones, deep below the substratum, adrift in the current, and in the surface film.

Hence, freshwater system that exhibit greater primary productivity will normally produce more invertebrates as well as small fish. More invertebrates and small fish will normally mean more food supply to support the population of large fish.

Hence, more fish biomass is expected in a water body where primary productivity is high. However, high productivity of the aquatic system does not guarantee more fish population. Each fish species is best adapted to certain conditions, and will not do well where these conditions do not exist.

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(c) Invertebrates in Wetlands

Depending upon the wetland sediments, invertebrates can reach high densities (over 100,000 per square meter), they may be substantial drivers of wetland biogeochemical processes.

For instance, growing evidence suggests that aquatic invertebrate activity can enhance greenhouse gases emissions. For example the burrows of midge larvae emit high concentrations of nitrous oxide.

(3) Fishes and Other Vertebrate Taxa

Oligotrophic lakes (lakes having low nutrient content) support only a few fish species. Lake trout is one such species that is adapted to cold, well-oxygenated, Clear water lakes, with relatively little algal productivity. Contrarily, fish species like bass or walleye are well adapted to life in warmer, shallower, more productive lakes.

(a) Fish and Other Vertebrates in Lentic Water

Fishes are extensively present in lentic water system as they have a wide range of physiological tolerances like to temperature or oxygen saturation. Further, fishes are mobile in nature and hence can move from one zone to another in search of favourable/optimal conditions. Also, fish alters its habitat according to its life history. For instance, hatching in a sediment nest, then moving to the weedy benthic zone to develop in a protected environment with food resources, and finally into the pelagic zone as an adult. Fishes exhibit a wide range of feeding habits. Herbivore fishes, feeds on periphyton and macrophytes or pick phytoplankton out of the water column. Carnivore's fishes or other carnivore vertebrates present in the lentic water system feds on zooplankton in the water column, insects at the water's surface, on benthic structures, or in the sediment (insectivores), and those that feed on other fishes (piscivores). Further, detritivores feed on dead and decaying organic matter. Omnivore's fishes can feed on a wide variety of prey consisting of floral, faunal, as well as detrital material. Lastly, parasitic fishes depend upon other large fishes or vertebrate for their nutrition. Apart from fish, other vertebrate taxa are also present in the lentic water system such as frogs, salamanders, reptiles, alligators, snakes as well as turtles. As seen above, biota present in the lentic system are linked in complex web of trophic relationships. The entire biota can be categorized in a chain system having a specific trophic level, that is primary producers, herbivores, primary carnivores, secondary carnivores, etc.

(b) Fish and Other Vertebrates in Lotic Water

Fishes are perhaps the best-known inhabitants of lotic water system. The capability of a fish species to thrive in flowing waters depends upon the speed at which it can swim as well as the duration for which it can maintain a particular speed. Swimming requires a lot of energy and hence fishes only spend a short period in full current either to feed or change locations. Instead, they prefer to stay close to the bottom or the banks, behind obstacles or sheltered from the current. Few fish species are completely benthic and never venture into the open water flow. Fish exhibit several adaptations to survive in the water flow like dorso-ventrally flattened body, streamline body structure, eyes on top, lateral line system, etc.

Lotic systems typically connect to each other, forming a path to the ocean, i.e. spring $\rightarrow$ stream $\rightarrow$ river $\rightarrow$ Ocean, and several fish species have life cycles that require stages both in fresh as well as salt water. For instance, Anadromous fish is born in freshwater, spends most of its life in seawater and then, returns to freshwater to spawn whereas Catadromous fish is born in seawater, spends most of its life in freshwater and then, returns to seawater to spawn. Anadromous and Catadromous fish are two types of fish who live in a separate habitat than the habitat they have spawn. Salmon, smelt, striped bass, shad, and sturgeon are examples of Anadromous fish while eels are an example of Catadromous fish. Other vertebrate taxa that inhabit lotic systems include amphibians, such as salamanders, reptiles (e.g. snakes, turtles, crocodiles and alligators) various bird species, and mammals (e.g. otters, beavers, hippos, and river dolphins).

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(c) Fish and Other Vertebrates in Wetlands

The main animals found in a wetland Include fish, amphibians, reptiles, mammals and monotremes (mammals that lay eggs). A few wetlands are capable of sustaining thousands of species of animals. For instance, Dangars Lagoon out near Uralla supports over three thousand species of birds. Fauna in a wetland helps to maintain the flora in a wetland by eating and re-pollinating all the plants.

Check Your Progress

15. Define the bicarbonate equilibrium.
16. Which elements are the major contributors to freshwater acidification?
17. What do you understand by primary production?

2.9 ANSWERS TO 'CHECK YOUR PROGRESS'

1. The major focus of chemical limnology is on the cycling of various chemical substances in freshwater bodies like lakes and rivers. A lot of factors affect the chemistry of lakes and rivers like the chemical composition of the soil in the watershed, the atmosphere (mass of air surrounding Earth) as well as the composition of the riverbed or lake bottom.
2. Dissolved oxygen characterizes the concentration of oxygen in an aqueous solution and refers to the free oxygen dissolved in water. The amount of dissolved oxygen in the water is an indicator of the self-purification ability of the water body.
3. Biological oxygen demand (BOD) or Biochemical Oxygen demand (BOD) is referred as the amount of oxygen needed or demanded by aerobic microorganisms to break down the organic matter present in a certain sample of water at a specific temperature over a given period of time.
4. 'Inland waters' are aquatic-influenced environments located within land boundaries. This includes those located in coastal areas, even those adjacent to marine environments. Inland water systems can be fresh, saline or a mix of the two (brackish water). Inland waters include lakes, rivers, ponds, streams, groundwater, springs, cave waters, floodplains, as well as bogs, marshes and swamps, which are traditionally grouped as inland wetlands.
5. Salinity refers to the total concentration of the ions present in lake water and is generally evaluated from the concentration of sodium (Na), potassium

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(K), magnesium (Mg), calcium (Ca), carbonate, silicate as well as halide concentrations.

6. Phosphorous is considered to be the most limiting nutrient in the fresh-water system because the amount of phosphorous available to organisms is much less than the amount required when compared to other elements.
7. Secondary salinity refers to salinity resulting from anthropogenic activities usually land development and agriculture.
8. A biogeochemical cycle is referred to as the pathway via which a chemical substance is turned over or moves through the biotic (biosphere) and the abiotic (lithosphere, atmosphere and hydrosphere) compartments of Earth.
9. The term nitrification refers to the conversion of ammonium to nitrate. Nitrification is the biological oxidation of ammonia to nitrite followed by the oxidation of the nitrite to nitrate occurring through separate organisms or direct ammonia oxidation to nitrate.
10. Silica enters into the aquatic environments by weathering of rock-forming silicate minerals by acidic dissolution.
11. Nitrogen fixation refers to the conversion of N_2 to ammonia or related nitrogenous compounds, by Blue green algae (Cyanobacteria) like Anabaena, Nostoc, Azolla, etc.
12. By the process de-nitrification, NO_3^- in water is converted into atmospheric N_2, nitric oxide or nitrous oxide.
13. The phosphate salts dissolved in water are absorbed by the plants. The aquatic plants absorb inorganic phosphorus from lower layers of water bodies.
14. Sulphur is released into the atmosphere via:
    - Burning of fossil fuels
    - Volcanic activities
    - Decomposition of organic molecules.
15. The chemical conversions among carbon dioxide and carbonic acid is referred to as the bicarbonate equilibrium. The bicarbonate equilibrium can be denoted as:

    $CO_2+H_2O \Leftrightarrow H_2CO_3 \Leftrightarrow H^{+}+HCO_3 \Leftrightarrow 2H^{+}+ CO_3^{-}$

    Where: CO_2- Carbon dioxide, H_2O- Water molecule, H_2CO_3- Carbonic acid, HCO_3- Bicarbonate ion.
16. The major contributors to freshwater acidification are sulphur oxides and nitrogen oxides. In addition to sulphur oxides and nitrogen oxides, low buffering capacities of freshwater ecosystems can also lead to freshwater acidity. Biodiversity is affected by increase in the acidification of the freshwater ecosystem.
17. Primary production refers to the synthesis of organic compounds from atmospheric or aqueous carbon dioxide. It chiefly occurs via the process of photosynthesis, which utilizes light as its source of energy, however, it also occurs via chemosynthesis, which uses the oxidation or reduction of inorganic chemical compounds as its source of energy.

2.10 SUMMARY

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- Chemical limnology is the study of the cycling of various chemical substances in freshwater bodies like lakes and rivers.
- Presence of hydronium ions in the water indicates the acidity (charge) of the water, which strongly affects the kind of flora or fauna that can inhabit the water bodies.
- DO is the abbreviation used for Dissolved Oxygen. Dissolved oxygen characterizes the concentration of oxygen in an aqueous solution.
- Oxygen is released into the water bodies by biological production or in simple terms by the process of photosynthesis.
- The stratification of water temperature and growth of phytoplankton were the key factors determining the vertical distribution of dissolved oxygen.
- Eutrophication refers to the process in which a water body becomes overly enriched with nutrients, leading to excessive growth of algae and plankton.
- Biological oxygen demand (BOD) or Biochemical Oxygen demand (BOD) is referred as the amount of oxygen needed or demanded by aerobic microorganisms to break down the organic matter.
- The chemical oxygen demand (COD) represents the amount of oxygen necessary for the aerobic biological oxidation (breakdown) of the organic substances.
- Inland waters include lakes, rivers, ponds, streams, groundwater, springs, cave waters, floodplains, as well as bogs, marshes and swamps.
- Salinity refers to the total concentration of the ions present in lake water and is generally evaluated from the concentration of sodium (Na), potassium (K), magnesium (Mg), calcium (Ca), carbonate, silicate as well as halide concentrations.
- Nitrogen and its various compounds appears in different forms in freshwater bodies like free nitrogen in solution, organic compounds, ammonia, nitrite as well as nitrate.
- Those lakes that have salinities in excess of 3 grams per litre are called as Saline lakes.
- Salinity affects crop production, pastures as well as trees by interfering with nitrogen uptake, reducing growth and stopping plant reproduction.
- Salinity affects the quality of water for drinking, human consumption as well as for agricultural purposes, with severe economic, social and environmental consequences for both rural and urban communities.
- A biogeochemical cycle is referred to as the pathway via which a chemical substance is turned over or moves through the biotic (biosphere) and the abiotic (lithosphere, atmosphere and hydrosphere) compartments of Earth.
- The balance of the chemical elements is preserved by a cyclic movement through the tissues of plants and animals.
- In the gaseous cycle, the main reservoir of nutrients is either the atmosphere or the hydrosphere (ocean).

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- In the sedimentary cycle, the main reservoir is the lithosphere and the sedimentary as well as other rocks of the earth's crust.
- Migration and subsequent death of the organism can add significant nutrients to the ecosystem.
- Silicon is known to be the second most abundant element in the Earth's crust, 27% by weight (Faure, 1986), exceeded only by oxygen.
- Silica forms the skeleton structures of numerous aquatic plankton like diatoms, radiolarians as well as the spicules of sponges.
- Iron is an essential micronutrient for almost every life form present on earth.
- The iron cycle (Fe) is the biogeochemical cycle of iron via the atmosphere, hydrosphere, biosphere and lithosphere.
- There are bacteria that oxidise manganese to insoluble oxides, and others that reduce it to Mn^{2+} in order to use it.
- Nitrogen fixation refers to the conversion of N_2 to ammonia or related nitrogenous compounds.
- When plants or animals die, the nitrogen present in the organic matter is released back into the soil.
- Sulphur is a yellow, brittle, tasteless, odourless non-metal. It is one of the most abundant elements in nature and is present in almost all kinds of proteins.
- Sulphur cycling, one of the active biological processes in aquatic sediments, is catalysed by sulphate-reducing prokaryotes (SRPs) and sulphur-oxidizing prokaryotes (SOPs).
- Inorganic carbon is present in the atmosphere, chiefly in the form of carbon dioxide (CO_2) having a concentration of around 350 ppm.
- When carbon dioxide is dissolved in water, it can exist in a variety of forms, depending on the pH of the aquatic system.
- Biodiversity is affected by increase in the acidification of the freshwater ecosystem.
- Net primary production is the rate at which all the autotrophs in an ecosystem produce net useful chemical energy.
- The ratio of productivity to biomass (P/B ratio) estimates the turnover rates of energy flow relative to biomass; P/B values generally decrease with increasing trophic level.
- The temperature keeps on decreasing gradually from the surface to the bottom of the water body.

2.11 KEY TERMS

- **Biological Oxygen Demand (BOD)**: Biological oxygen demand (BOD) or Biochemical Oxygen demand is referred as the amount of oxygen needed or demanded by aerobic microorganisms to break down the organic matter present in a certain sample of water at a specific temperature over a given period of time.

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- **Chemical Oxygen Demand (COD):** The chemical oxygen demand (COD) represents the amount of oxygen necessary for the aerobic biological oxidation (breakdown) of the organic substances in a given water body or sample to carbon dioxide (CO_2) and water (H_2O) if the organics are actually biodegradable.
- **Primary salinity:** Primary salinity refers to naturally occurring salinity.
- **Saline lakes:** Those lakes that have salinities in excess of 3 grams per litre are called as Saline lakes.
- **Biogeochemical cycle:** A biogeochemical cycle is referred to as the pathway via which a chemical substance is turned over or moves through the biotic (biosphere) and the abiotic (lithosphere, atmosphere and hydrosphere) compartments of Earth.
- **Manganese oxidizing bacteria:** Bacteria that oxidise manganese to insoluble oxides.
- **Nitrogen fixation-** Nitrogen fixation refers to the conversion of N2 to ammonia or related nitrogenous compounds.
- **Nitrification:** The term nitrification refers to the conversion of ammonium to nitrate.
- **Bicarbonate equilibrium:** The chemical conversions among carbon dioxide and carbonic acid is referred to as the bicarbonate equilibrium.
- **Primary production**: In ecology, primary production refers to the synthesis of organic compounds from atmospheric or aqueous carbon dioxide.
- **Net primary production**: Net primary production is the rate at which all the autotrophs in an ecosystem produce net useful chemical energy.
- **Secondary production:** The productivity of autotrophs, such as plants, is called primary productivity, while the productivity of heterotrophs, such as animals, is called secondary productivity**.**

2.12 SELF ASSESSMENT QUESTIONS AND EXERCISES

Short-Answer Questions

1. How the amount of dissolved oxygen in the water indicate about the self-purification ability of the water body?
2. How the dissolved oxygen (DO) level helps to determine the amount of organic matter present in water?
3. Which factors affect the concentration of oxygen in inland waters.
4. Define oil spills. How does it affect aquatic life?
5. What is chemical oxygen demand (COD)? How it is important in accessing the quality of a given water body.
6. Write the difference between primary and secondary salinity.
7. What are the ways by which nutrients enters into the ecosystem.

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8. What is difference between open and closed type of nutrient flow?
9. Define ammonification.
10. Write the difference between the composition of sea and fresh water.
11. Why Iron is considered as an essential micronutrient for almost every life form present on earth.
12. How the iron cycle influences other cycles like nitrogen, phosphorous and sulphur cycles.
13. How Phosphorus return back to the Ecosystem?
14. What are two types of biogeochemical cycles?
15. Why concentration of carbon dioxide in the atmosphere is continuously increasing.
16. What are the various natural sources of sulphur?
17. What do you understand by acidification of fresh-water system?
18. List down the harmful effects of acidification on aquatic ecosystems.
19. How the primary productivity by photosynthesis is estimated?

Long-Answer Questions

1. What is biological oxygen demand? How it is evaluated? List the factors influence the BOD of water.
2. Discuss the effects of salinity in freshwater system in detail.
3. Explain the characteristics of biogeochemical cycles.
4. Analyse the input and output of nutrients (addition) to the ecosystem.
5. Explain the term biogeochemical cycles. What are the types of biogeochemical cycles?
6. Briefly describe the human impact on aquatic phosphorous cycle.
7. Analyse that with a change in pH of the aquatic system there will be a corresponding change in the relative concentration of bicarbonate, carbonate and carbonic acid.
8. Explain the buffering Capacity of Freshwater ecosystem.
9. Briefly describe silicon and iron cycles in fresh water ecosystem
10. Write the various steps in the sulphur cycle in detail.
11. Describe nitrogen cycle in detail.

2.13 FURTHER READING

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UNIT 3 BIOLOGICAL LIMNOLOGY

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Structure

3.0 INTRODUCTION

Limnology correctly encompasses an integration of physical, chemical, and biological components of inland aquatic ecosystems of the drainage basin, movements of water through the drainage basins, and biogeochemical changes that occur en route, and within standing (lentic) waters. Limnology is closely related to aquatic ecology and hydrobiology, which study aquatic organisms and their interactions with the abiotic (non-living) environment. Biological limnology is directed at understanding the animals, plants, and microorganisms that live in lakes and rivers. The patterns of distribution of these various organisms depend on the geology, physics, and chemistry of the lake or river. For example, plants require light in order to grow. Because water is very effective at absorbing light, plants must either grow near the shore, where the water is shallow or they must float near the surface of the water. Biological limnology aims at understanding the flora and fauna; existing in the freshwater bodies like lakes, ponds, streams, rivers, etc.

Understanding of the causal mechanisms operating in and controlling our natural world is a primary objective of limnology because of the premier importance of fresh water for the well-being of humankind. The greater our understanding, the higher the probability to predict accurately patterns of events within aquatic ecosystems in response to human manipulations and disturbances.

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Biological limnology encompasses the distribution and adaptation of organisms that inhabit inland waters, their functions and behaviours, their interactions such as competition and predation, and their individual and collective metabolism. The primary goal of the Biological Limnology is to develop a working knowledge of the principles and literature on the ecology and biology of aquatic organisms. Much of the focus will be on the organisms of lentic and lotic ecosystems.

Plankton are the diverse collection of organisms found in water (or air) that are unable to propel themselves against a current (or wind).The individual organisms constituting plankton are called plankters. In the ocean, they provide a crucial source of food to many small and large aquatic organisms, such as bivalves, fish and whales. Planktonic organisms include protists (allegedly simple, unicellular, or colony-forming algal primary producers and their protozoan consumers), microorganisms, and certain types of small metazoan animals, all sharing a common liability to passive entrainment in water currents, generated by tide, wind, convection, gravity, and the rotation of the earth. Phytoplankton are the autotrophic (self-feeding) components of the plankton community and a key part of ocean and freshwater ecosystems. Zooplankton are the animal component of the planktonic community. They are heterotrophic (other-feeding), meaning they cannot produce their own food and must consume instead other plants or animals as food. In particular, this means they eat phytoplankton. Zooplankton are generally larger than phytoplankton, mostly still microscopic but some can be seen with the naked eye.

In this unit you will study about freshwater Biota, flora, fauna general characters and classification of fresh water biota, lentic communities, lotic communities, plankton, phytoplankton and zooplankton

3.1 OBJECTIVES

After going through this unit you will be able to:

- Discuss freshwater Biota, flora, fauna general characters and classification
- Explain lentic communities
- Define lotic communities
- Elaborate on plankton
- Understand phytoplankton
- Explain zooplankton

Biological limnology

Biological limnology aims at understanding the flora and fauna; existing in the freshwater bodies like lakes, ponds, streams, rivers, etc. The patterns of distribution of flora and fauna within these freshwater bodies depends on their geology, physics, and chemistry. For instance, plants need sunlight to grow. However, plants must either grow near the shore, where the water is shallow or they must float near the surface of the water where it can effectively absorb the sunlight.

3.2 FRESHWATER BIOTA- FLORA AND FAUNA

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Fresh water (or freshwater) is any naturally occurring source of water; containing low concentrations of dissolved salts and other total dissolved solids. Freshwater habitats occupy a relatively small portion of earth‘s surface as compared to the marine and terrestrial habitats. We know that 97% of the earth’s water is in the oceans or sea; and it is referred as saline water. Only 3% of the total water present on the continents is freshwater.

As the sun’s intensity is affected by the seasonal changes, plants generally flourish well in the spring season and fall/die off as soon as the light level decreases. Similarly, animals need dissolved oxygen (DO) to breathe and carry out their metabolic activities. Warm water holds less dissolved oxygen (DO) as compared to cold water. Consequently, this effects the kind of fauna or flora present in a water body. For instance, trout, which require a lot of dissolved oxygen, are more often observed in cold lakes and rivers. On the other hand, Bass, which require less dissolved oxygen can be observed in warmer lakes as well as the surface waters of lakes. The most critical challenge faced by the limnologist is the introduction of exotic species into freshwater bodies, i.e., lakes or rivers. Frequently, humans introduce new species into lakes and rivers and in a few cases, these newly introduced species grow faster as compared to the local species and can inhabit almost the entire water body in no time. For instance, in 1985 the zebra mussel was released into the Great Lakes of the United States. These mussels reproduced so fast in the Great Lakes that soon they become a widespread problem like, clogging the sewage pipes and overgrowing docks and piers.

A variety of biotic communities are known to exist in freshwater namely; phytoplankton’s, zooplanktons, nekton, neuston, benthos, etc. The freshwater communities are the primary determining factors of the productivity of their respective ecosystems.

Freshwater biota may be classified on the basis of their position in the energy or food chain as:

(1) **Autotrophs (Producers):** These includes the green plants and the chemosynthetic microorganisms.

(2) **Phagotrophs (Macroconsumers):** These includes primary, secondary, and tertiary consumers, including herbivores, predators, parasites, etc.

(3) **Saprotrophs (Microconsumers or Decomposers):** These can be further sub-classified according to the nature of the organic substrate that has been decomposed.

This section emphasize on the general characteristics of the different biotic communities present in fresh water system

In this section, we will discuss the flora and fauna of freshwater system

3.2.1 General Characters of Biota Present in Freshwater System

Freshwater consist of biota (both flora as well as fauna) from all the five kingdom namely; Kingdom Monera, Kingdom Protista, Kingdom Fungi, Kingdom Plantae, and Kingdom Animalia. The Kingdom Monera includes prokaryotic organisms like bacteria, which lacks a well-organized nucleus as well as membrane bound organelles; Kingdom Protista includes all unicellular and colonial eukaryotes like algae, diatoms, and protozoans which are unicellular eukaryotic organisms, having a well-organized nucleus, membrane bound organelles, and exhibit both autotrophic and heterotrophic mode of nutrition; Kingdom Fungi includes mushrooms, Rhizopus, etc., which are multicellular eukaryotic saprophytic organism; Kingdom Plantae includes autotrophic, multicellular eukaryotic organisms whose cell walls are made up of cellulose; and Kingdom Animalia include multicellular eukaryotic organisms lacking a cell wall.

3.2.2 Classification of Freshwater Biota

Freshwater biota may be classified on the basis of their mode of life

(1) **Phytoplankton:** Phytoplankton are small microscopic, unicellular, and photosynthetic organisms which freely float on water bodies. Phytoplankton are composed of both eukaryotic as well as prokaryotic species which colonizes the upper euphotic part of the water column ranging from freshwater to marine conditions. They also exhibit amazing adaptations to remain in floating conditions. The range of the Phytoplankton cells can vary in size from about 1 ìm to 1 mm. Like terrestrial plants, these tiny primary producers need sunlight, nutrients, as well as carbon dioxide for their growth and multiplication. Phytoplankton contains chlorophyll, which helps them to synthesize food in the presence of sunlight. Therefore, they help in maintaining not only the carbon dioxide level but also help to alleviate global warming to some extent. Physical processes like wind and current play a substantial part in their distribution, particularly in estuarine and marine conditions. Phytoplankton act as a primary link in energy pathway to higher trophic level via several food chains.

(2) **Zooplankton:** The name zooplankton is derived from the Greek words: *zoon,* animal; *planktons*, wandering. Zooplanktons are microscopic, unicellular, or multicellular forms, with size ranging from a few microns to a millimetre or even more. Apart from the size variations, zooplanktons exhibit many differences in morphological features as well as taxonomic positions; consisting of representatives from almost every taxon of the animal kingdom. They are diverse, gentle, and beautiful groupings of animals that drift in the aquatic bodies and add substantiality to the faunal biodiversity of aquatic bodies. They play a significant role in the marine food web. They help in transferring organic energy obtained from unicellular algae to higher trophic levels like pelagic stocks. They act as a food source for larval as well as juvenile fish, hence their reproductive cycles, growth, as well as their survival rates are also an essential factors influencing the fishery. Zooplanktons can

further be classified into different categories on the basis of their life cycle, size, organization of the body, etc.

- **Pleuston:** Pleuston refers to floating organisms present in the aquatic system
- **Nekton:** The term nekton is used for actively swimming organisms of the aquatic system, e.g., Fish, amphibians, swimming large insects, etc.
- **Neuston:** Neuston refers to organisms that are present on the water surface
- **Benthos:** Benthic organisms are present at the bottom of the aquatic ecosystem and are sessile, burrowing, creeping, etc. For example, clams and deposit feeders, such as, snails.
- **Periphytons or Aufwuchs:** These are the plants and animals that attach or cling to the stems and leaves of rooted plants or other surfaces projecting above the bottom.

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3.3 LENTIC COMMUNITIES

Those aquatic system which contains standing or stagnant water are referred to as Lentic aquatic systems. Lentic water systems are closed system which are generally formed in small or large depressions on earth's surface; lacking any exit for the water to flow out. Natural processes in the long run transforms such a lentic body into a swamp or a marsh, a wetland, and finally to a dry land. Ponds and lakes are familiar examples of such systems.

A lentic aquatic body is divided into four zones.

(1) Littoral Zone: Shallow water present around the margins of the aquatic body is referred to the Littoral zone. Plenty of light is available in this zone and supports the growth of rooted plants.

(2) Limnetic Zone: Limnetic zone is the zone of open waters which are deeper as well. Availability of plenty of light in this zone promotes active photosynthesis as well as growth of free-floating autotrophs like planktons.

(3) Profundal Zone: Profundal zone is present beneath the limnetic zone and receives very less light. Hence, this zone is known as aphotic zone in contrast to euphoric zone (limnetic and littoral regions) which are comparatively well illuminated.

(4) Benthic Zone: Benthic zone is present beneath the profundal zone. Benthic zone is present near the bottom of the aquatic body. Profundal as well as benthic zones are characterised by the presence of heterotrophs; which survive on dead and decaying organic material coming from the limnetic zone present above.

The major characteristics of lentic aquatic system are as follows:

- Lentic systems derive most of their waters from rains, surface run-offs or from underground sources.
- Lentic systems are closed systems.

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- There is a marked stability in the physicochemical characteristics of water quality, i.e., the quality of water remains same for several years in lentic water system.
- The biological productivity of a lentic system is influenced by its physio-chemical properties.
- Variations in the physio-chemical properties of water affect the composition of the living communities residing in it.
- Periods of bright sunshine are usually associated with a rich growth of phytoplankton.
- Total surface area of lentic water body is more essential in evaluating the overall produc-tivity of a lentic water system rather than total volume of the water or the depth of the water body.
- All substances of consistent nature or products of decay and mineralization of organic matter as well as the decomposition products of pollutants discharged in the aquatic body stay in the lentic water system.
- Biotic community present in the lentic water system is often affected by the presence of these materials.
- Stratifica-tion causes different layers of a lentic water to have different oxygen content and nutrient status.

A biotic community, also known as a '*biota*' or '*biocoenosis*', is the group of organisms that live together and interact with each other within an environment or habitat. Together, the biotic community and the physical landscape or abiotic factors make up an ecosystem. Communities consist of a group of different species, which partake in direct and indirect biotic interactions, such as predator-prey interactions, herbivory, parasitism, competition, and mutualisms. Alternatively, the interrelationships may take a more diffuse route, such as an organism that creates certain necessary climatic conditions, or the one that acts as a substrate for another organism. The biotic communities associated with lentic water system are:

(1) Bacteria: Bacteria are present in all regions of lentic waters. Free-living bacterial forms are associated with decomposing organic material, or are present on the surfaces of rocks as well as plants, suspended in the water column, and in the sediments of the benthic and profundal zones. A few other bacterial forms are associated with gut of lentic animals as parasites or in commensal relationships. Bacteria play an essential function in system metabolism via nutrient recycling. Majority of bacteria in lentic water system depends upon dead and decaying organic matter to obtain their energy. These bacteria are then eaten up by the protozoa which in turn are consumed by zooplankton and then further up the trophic levels.

(2) Primary Producers: Phytoplankton and periphytons are the chief primary producers in the lentic water system. Phytoplankton are seen drifting in the water column of the pelagic zone. However, several phytoplankton have a higher density and sink to the benthic region. Periphytons remains attached to the substrate covering almost the entire benthic surfaces. Phytoplankton as well as periphyton serve as an important food source and chief oxygen

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producers in the lentic system. Further, plants or macrophytes are found in both the benthic and the pelagic zones and can be categorized according to their way of growth:

(a) **Emergent Macrophytes:** Emergent macrophytes are rooted in the substrate, however, their leaves and flowers extends into the air. They are present near the shoreline.

(b) **Floating-Leaved Macrophytes:** Floating-leaved macrophytes are rooted in the substrate but with floating leaves,

(c) **Submerged Macrophytes:** Submerged macrophytes are not rooted in the substrate and floating beneath the surface

(d) **Free-Floating Macrophytes:** Free-floating macrophytes are not rooted in the substrate and keeps on floating at the surface. They can be present anywhere on the surface of lentic water.

Lentic systems gain most of their energy from photosynthesis performed by aquatic plants and algae.

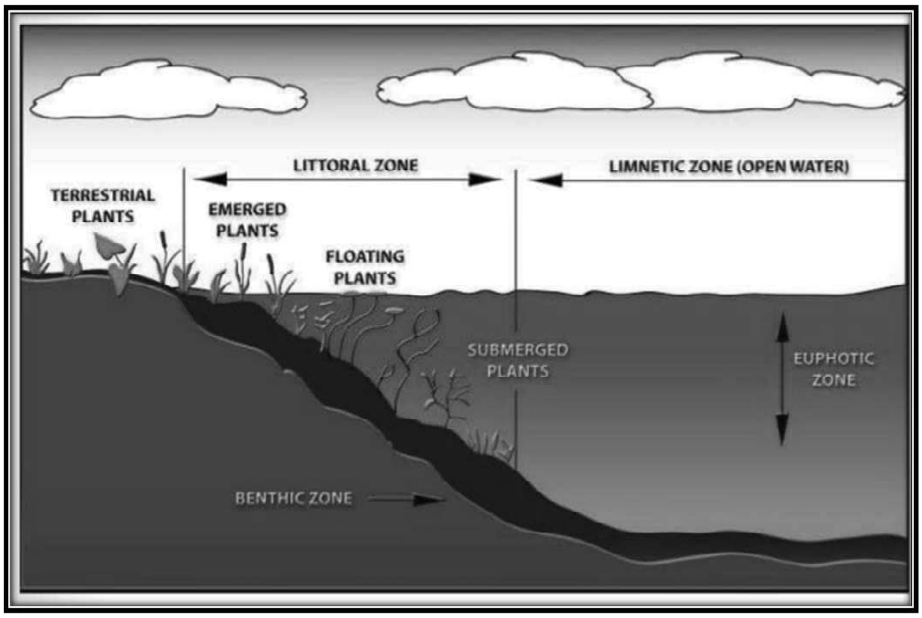

Fig.3.1 *Primary Producers in a Lentic Water Body*

Zooplankton and Invertebrates: The name zooplankton is derived from the Greek: *zoon,* animal; *planktos*, wandering. Zooplankters are microscopic, unicellular or multicellular forms with size ranging from a few microns to a millimetre or even more. Apart from the size variations, zooplanktons exhibit differences in morphological features as well as taxonomic positions consisting of representatives from almost every taxon of the animal kingdom. They are diverse, gentle, and beautiful groupings of animals that drift in the aquatic bodies and adds substantiality to the faunal biodiversity of aquatic bodies. They play a significant role in the marine food web. They help in transferring organic energy obtained from unicellular algae to higher trophic levels like pelagic stocks. They act as food source for larval as well as juvenile fish, hence their reproductive cycles, growth as well as survival rates are essential factors influencing fishery. Zooplankton have the ability to switch

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from laying regular eggs to resting eggs when there is a lack of food, temperatures fall below 2 °C, or if predator abundance is high. The invertebrates that inhabit the benthic zone are numerically dominated by small species and are species rich compared to the zooplankton of the open water. Invertebrates commonly found in the lentic water system include crustaceans, for example, crabs, crayfish and shrimp, molluscs, for example, clams and snails as well as numerous types of insects. All these organisms usually inhabits the areas of macrophytic growth having favourable conditions for their growth and survival like presence of food, optimal temperature, as well oxygen. However, some invertebrates are also found in the cold, dark, and low oxygen profundal zone. Zooplankton exhibits diverse food habits. For instance:

(a) **Protozoa:** They feed upon minute algae and bacteria. Utilisation of dissolved substances has been demonstrated in certain protozoa.

(b) **Metazoan:** In 1929, Neumann considered the relation of zooplankton as seston feeders into the 4 types namely:

a. **Grasping Type:** They touch and secure seston with the help of pseudopodia like Rhizopoda.

b. **Filtration Type:** It involves filtering of seston from water as animal moves.

c. **Sedimentation Type:** It involves capturing of seston via inducing water currents.

d. **Predatory Type:** They capture other organisms.

Fishes: Fishes are extensively present in lentic water system as they have a wide range of physiological tolerances like to temperature or oxygen saturation. Further, fishes are mobile in nature and hence can move from one zone to another in search of favourable/optimal conditions. Also, fish alters its habitat according to its life history. For example, hatching in a sediment nest, then moving to the weedy benthic zone to develop in a protected environment with food resources, and finally into the pelagic zone as an adult. Fishes exhibit a wide range of feeding habits. Herbivore fishes, feeds on periphyton and macrophytes or pick phytoplankton out of the water column. Carnivore fishes or other carnivore vertebrates present in the lentic water system feds on zooplankton in the water column, insects at the water's surface, on benthic structures, or in the sediment (insectivores), and those that feed on other fishes (piscivores). Further, detritivores feed on dead and decaying organic matter. Omnivore's fishes can feed on a wide variety of prey consisting of floral, faunal, as well as detrital material. Lastly, parasitic fishes depend upon other large fishes or vertebrate for their nutrition.

Other Vertebrates: Apart from fish, other vertebrate taxa are also present in the lentic water system, such as, frogs, salamanders, reptiles, alligators, snakes, as well as turtles. As seen above, biota present in the lentic system are linked in complex web of trophic relationships. The entire biota can be categorized in a chain system having a specific trophic level. For instance; primary producers, herbivores, primary carnivores, secondary carnivores, etc.

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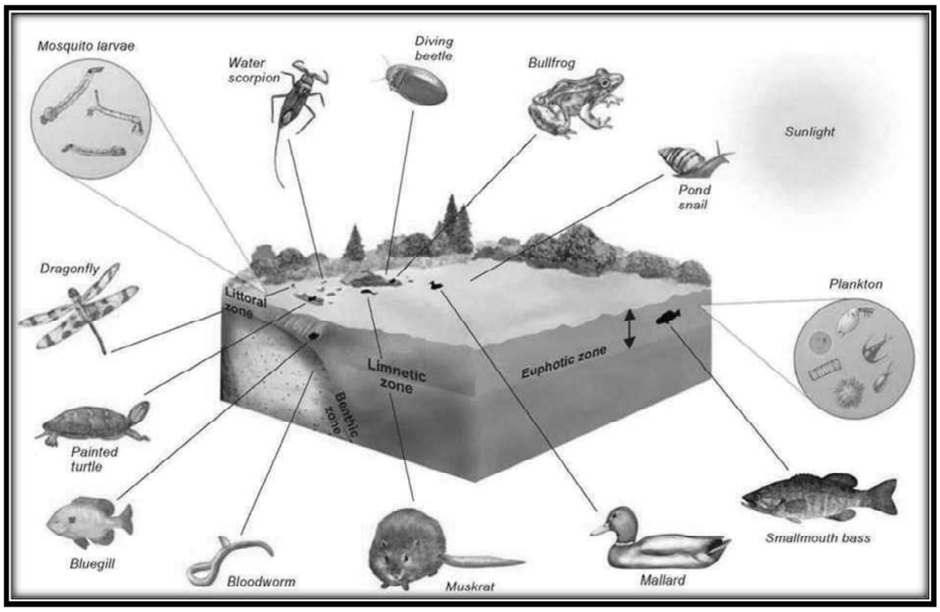

Fig. 3.2 *Biotic Communities in a Lentic Water Body*

3.3.1 Biotic Communities Present in Lakes

Lake consists of one or more basins, partially or completely connected to each other. All parts of the lake will have the same water level (except for the effects of wind, ice cover, and incoming rainfall). The lake usually does not have any connection to the ocean or sea water. A significant portion of the sediment suspended in the water will accumulate at the bottom of the lake. The average water volume of a lake must exceed a certain limit (e.g. more than 1 hectare). Lake is divided into zones namely; littoral zone, limnetic zone, profundal zone, and benthic zone.

The littoral zone adjoins the shore and extends down to a point known as the light compensation level or the depth at which the rate of photosynthesis equals the rate of respiration. The littoral zone of Lakes exhibits rich biodiversity having a variety of rooted /benthic plants as well as numerous phytoplankton. Rooted plants are generally seen in those areas where light penetrates efficiently to a specific depth. Emergent plants usually grow well in the riparian areas of water bodies. The rooted parts of these plants are attached to the soil near the shore whereas the chlorophyll-bearing portion of the plants are located on the surface of the water. For example *Typhala, Scirpus, Sagitaria* and *Pickerel* weeds. Deeper than the shore, there are floating leafy plants like water lillies- *Nymphaea* and *Potamageton*. Rooted weeds are present deep inside the littoral region of the lake, however, they are completely submerged. The major phytoplankton of the littoral zone are holophytic blue green algae (*Microcystis, Oscillatoria,* etc.), flagellets diatoms, and green algae (*Cosmarium, Staurastrum,* etc.). Figure 3.3 is depicting the macrophytes present in lake.

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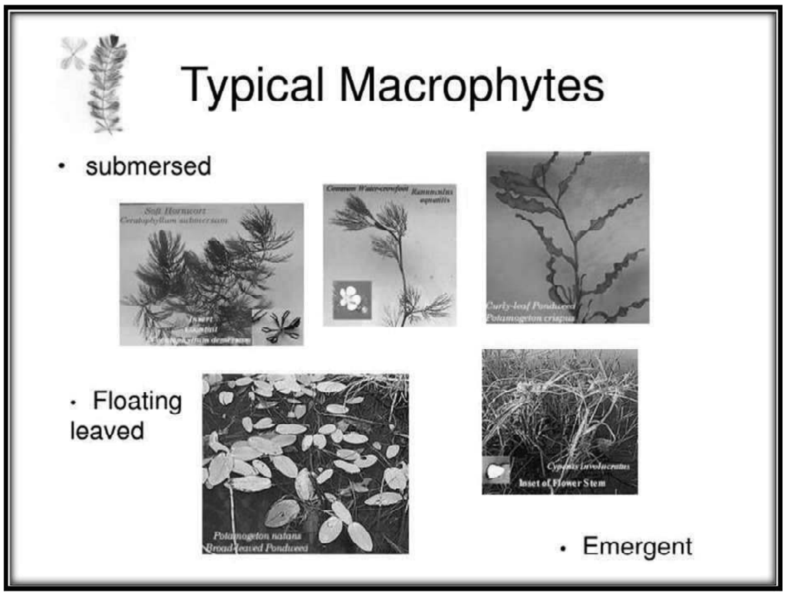

Fig. 3.3 Macrophytes Present in Lake

The faunal communities of this region includes; snails, insects, oysters, isopods, nymphs, etc., habituating either at the bottom of the mud or present above the mud. Other animals reside in plants that grow on the bottom or in any other object that grows from the top or from the bottom. This includes; *Dysticus, Stentor, Vorticella, Laccotrohes*, Glossophonia, Damsel flies nymphs, Dragonfly, Rotifers, for example, *Monostylla, Filinia, Asplanchna, Brachionus, Lecane and Keratella*, *Lymnaea, Bellamya,* Bryozoa*, Hydra,* etc., Further, the larvae of Chironomus are seen in rooted plants. Planarians can be found under the leaves of floating plants. Zooplankton in the littoral region are water flea such as *Daphnia, Moina*, Rotifers, such as; *Brachionus, Keratella,* and Ostracods. The nektons found are *Euglena, Coroxa, Dysticus, Paramecium, Gyrinus, Chaoborus, Ranatra,* Culex larva, etc.

Gerris: Water strider, also called pond skater or skimmer, are the insect of the family Gerridae (order Heteroptera), which numbers about 350 species. Water striders, often seen running or skating in groups over the surface of a pond or stream, are slender, dark coloured, and generally more than 5 mm (0.2 inch) long. They are also seen in the littoral zone. Periphyton of the littoral zone exhibits a zonation paralleling that of the rooted plants, but several species occur almost through the littoral zone. Among the periphyton forms, pond snails, damselfly nymphs, and climbing dragonfly nymphs, rotifers, flatworms, bryozoa, hydra, and midge larvae rest on, are attached to stems and leaves of the plants.

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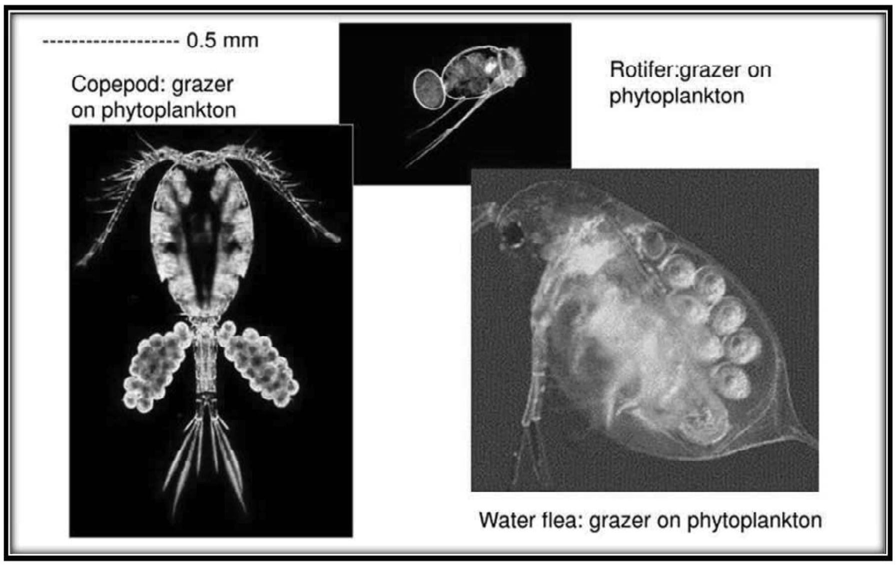

Fig. 3.4 *Zooplankton Present in Lake Water*

Figure 3.4 depicts the zooplankton present in lake water. The limnetic zone comprises all the waters outside the littoral zone and down to the light compensation level. The limnetic zone gets its oxygen supply from the photosynthetic activity of phytoplankton as well as from the atmosphere directly over the lake's surface. The community of the limnetic zone is mostly composed only of plankton, nekton, and sometimes neuston (organisms resting or swimming on the surface). Phytoplankton producers consist of diatoms, green algae, blue-green algae, and algae like green flagellates, chiefly the dinoflagellates, etc. Many microscopic creatures like *Volvox, Euglena, Phacus*, fish also occupy the limnetic zone. Zooplanktons comprises of Tardigrades ,such as *Macrobiotus*, Rotifer, such as *Rotaria, Philodina*, Copepods, snails. Frogs also live in the limnetic zone. The limnetic nekton consists almost entirely of fish. Figure 3.5 is depicting the phytoplankton present in lake water.

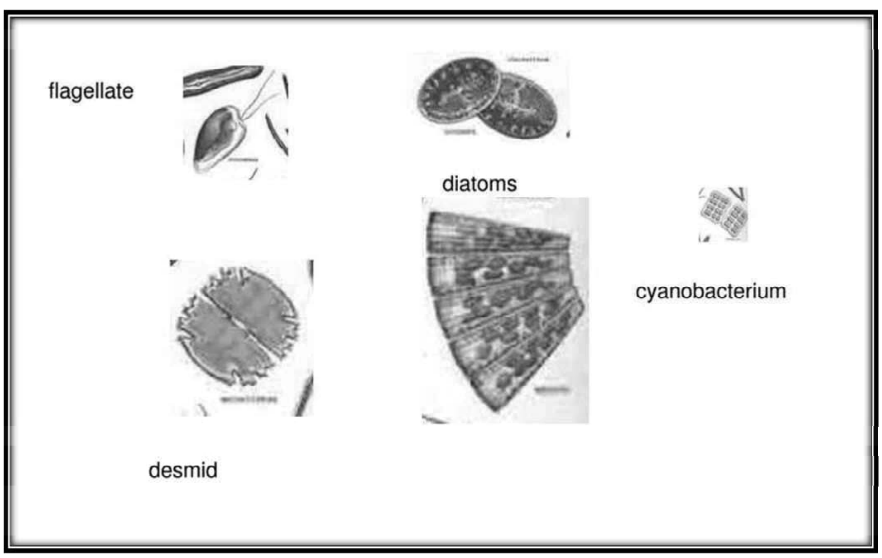

Fig. 3.5 *Phytoplankton Present in Lake Water*

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The bottom of a lake, which is beyond the depth of effective light penetration is referred to as the profundal zone. Profundal zone is mostly inhabited by blood worms, oysters, small calms, phantom larvae, annelids, fungi as well as some bacteria and most of them are anaerobic in nature. These animals can survive easily in low light as well as in low levels of oxygen. Autotrophic organisms fail to thrive in this area due to lack of sunlight. Their major source of energy is dead and decaying organic matter coming from the limnetic zone. All the organisms found in the profoundal region are parasitic, carnivores, or detrivores in nature. Large fish generally resides in the dark waters of the hypolimnion layer.

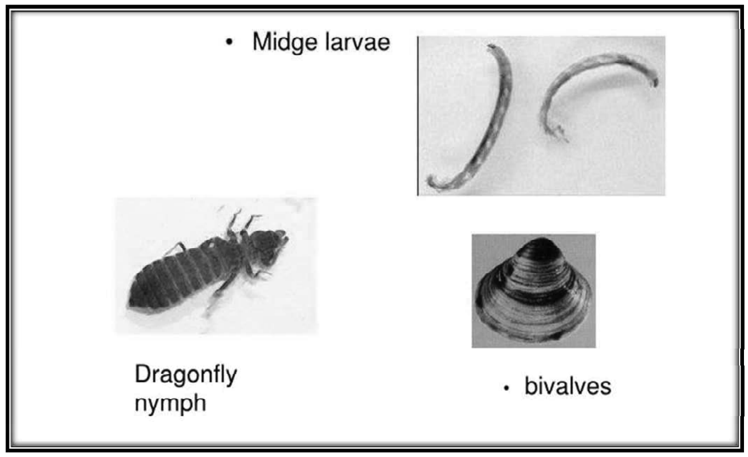

Fig. 3.6 *Benthic Communities of Lake Water*

Figure 3.6 is depicting the benthic communities of lake water. Rocks can be seen at the bottom of the new lake. Further, dead and decaying organic matter also keeps on accumulating in the benthic zone forming muddy or sandy bottoms that make benthos habitable. Most common benthic communities include larvae such as Midge larvae, pit-dwelling May-fly, oysters, snails, tube worms, etc. Figure 3.7 is depicting the nekton communities present in lake water.

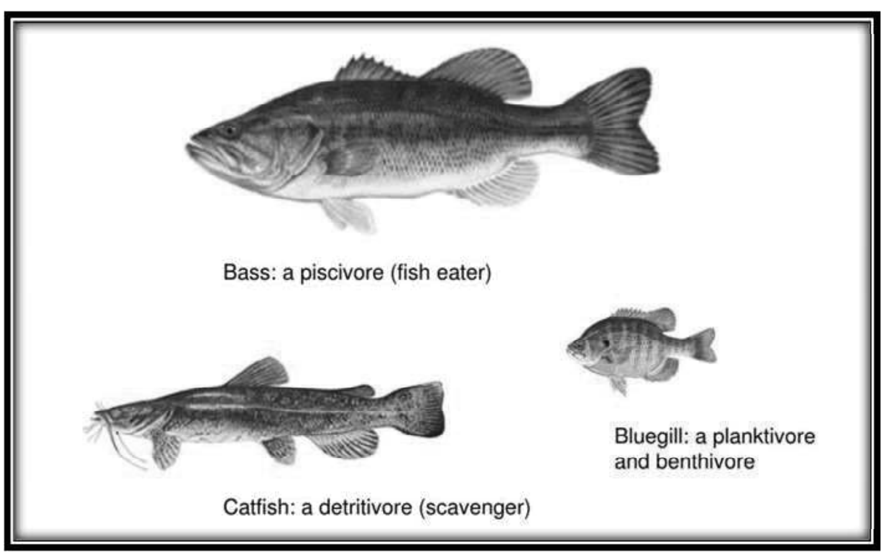

Fig. 3.7 *Nekton Communities Present in Lake Water*

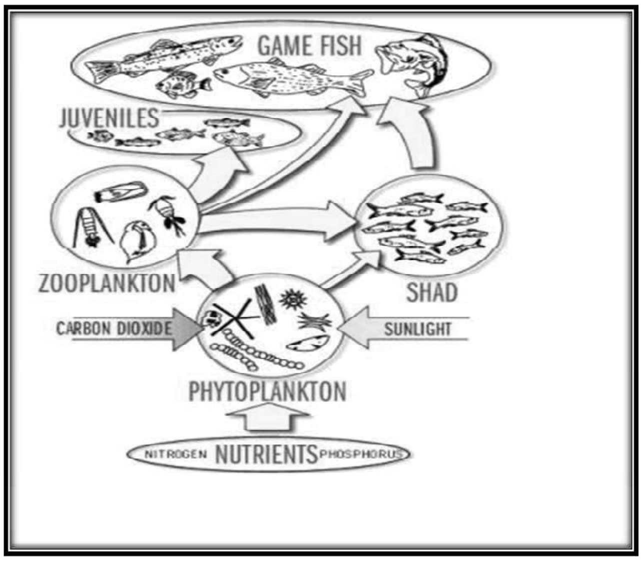

Fig. 3.8 *Typical Food-Web Operating in a Lake System*

Fig.3.8 is depicting the typical food-web operating in a lake system.

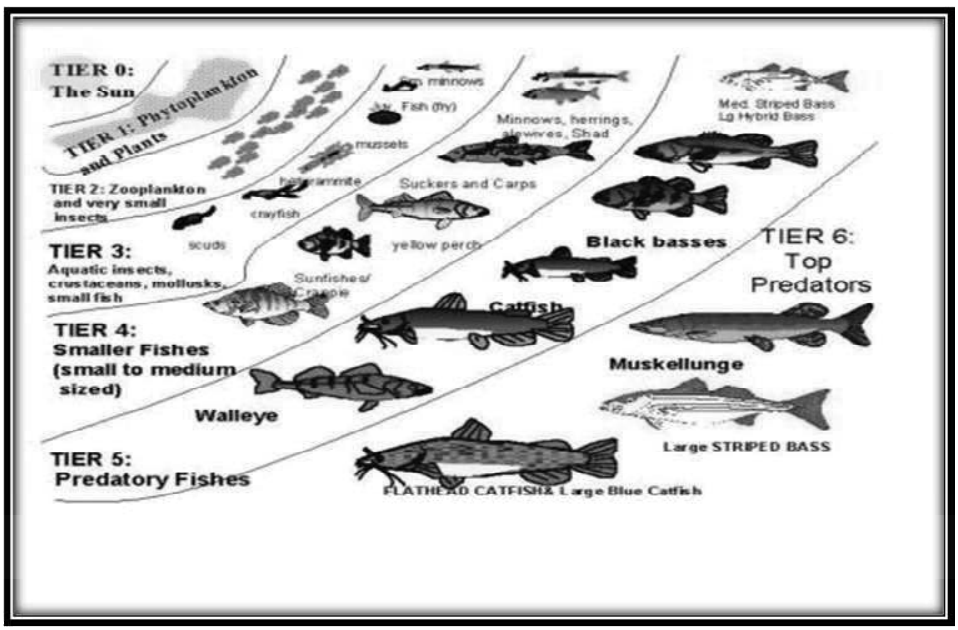

Fig. 3.9 *Biotic Communities Present at Different Trophic Levels*

Figure 3.9 is depicting the biotic communities present at different trophic levels in a lake system.

3.3.2 Biotic Communities Present in Ponds

Pond is defined as a small, shallow inland stagnant water body which is smaller than a lake. Ponds can be either natural or artificial. The marsh aquatic plants and various aquatic animals live mainly in the pond water depends upon the factors like; depth of the water in the pond, penetration level of sunlight, presence of food, presence of dangerous or harmful animals etc.

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Biotic components constitute the producers, consumers, and decomposers (microorganisms). The major producers of the pond ecosystem are as follows:

- Phytoplanktons like Oscillatoria, Anabaena, Eudorina, Volvox and Diatoms.
- Filamentous algae, such as Ulothrix, Spirogyra, Cladophora and Oedogonium.
- Floating plants Azolla, Salvia, Pistia, Wolffia and Eichhornia.
- Sub-merged plants Potamogeton and Phragmitis.
- Rooted floating plants Nymphaea and Nelumbo.
- · Macrophytes like Typha and Ipomoea.

Major Consumers of the Pond ecosystem are as follows:

- Primary consumers are zooplanktons like *Paramoecium* and *Daphnia*
- Secondary consumers like water beetles and frogs
- Tertiary consumers like duck, crane, etc.
- Top carnivores like large fish, hawk, man, etc.
- Benthos (bottom living animals) like mollusces and annelids, etc.

Decomposers are present in mud water and bottom of the ponds and helps in the recycling of nutrients by carrying out the process of decomposition. For example bacteria and fungi are decomposers.

3.3.3 Biotic Communities Present in Wetlands

Algae are chief part of a wetland ecosystem. Algae supply food for animals like small fish, insects and invertebrates. There are four main types of hydrophytes (plants that only live in or on water) in a wetland System. Submerged, floating, emergent shrubs and various amphibious trees.

- **Submerged Water Plants:** Submerged water plants are not rooted in the substrate and floating beneath the surface, i.e., they are completely submerged in water.
- **Emergent Water Plants:** Emergent water plants are rooted in the substrate, however, their leaves and flowers extends into the air. They are present near the shoreline.
- **Floating-Leaved Water Plants:** Floating-leaved water plants are rooted in the substrate but with floating leaves. Their roots can easily suck nutrients.

The Surrounding Plants as well as shrubs make up the swamp area that surrounds the wetland, usually in soils with a high saturated water level. These plants are adapted to wet conditions and hence can sustain life with a fair amount of water in their Cells. Depending upon the wetland sediments, invertebrates can reach high densities (over 100,000 per square meter), they may be substantial drivers of wetland biogeochemical processes. For instance, growing evidence suggests that aquatic invertebrate activity can enhance greenhouse gases emissions. For example the burrows of midge larvae emit high concentrations of nitrous oxide. The main animals found in a wetland Include Fish, Amphibians, Reptiles, Mammals and Monotremes (mammals that lay eggs). A few wetlands are capable of sustaining thousands of species of animals. For example Dangar's Lagoon out near Uralla supports over three thousand species of birds. Fauna in a wetland help maintain the flora in a wetland eating and re-pollinating all the plants. Figure 3.10 is depicting the food web in a wetland.

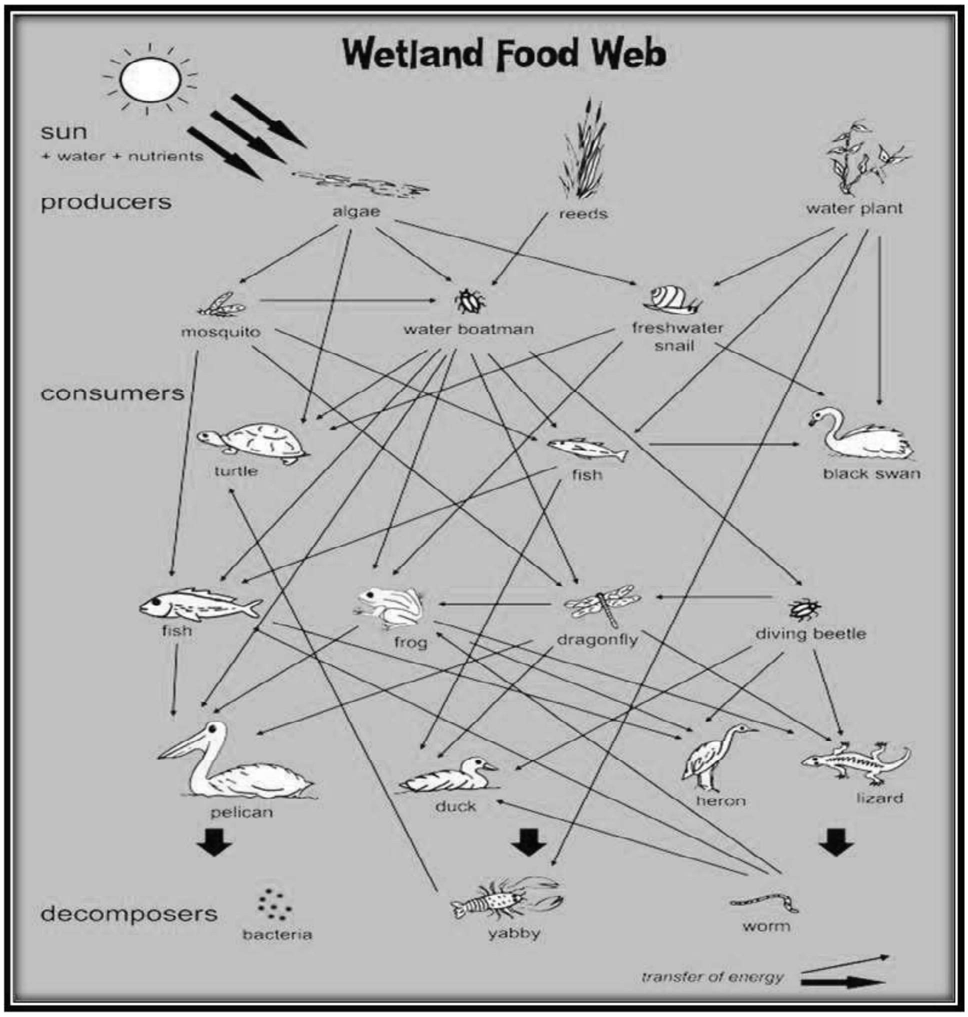

Fig. 3.10 Food Web in a Wetland

Check Your Progress

1. What is the aim of Biological limnology?
2. Define fresh water.
3. What are Periphytons or Aufwuchs?
4. What are lentic aquatic systems?
5. Define a biotic community.
6. From where do Lentic systems derive most of their waters?
7. Name the chief primary producers in the lentic water system.
8. Which fishes live in a separate habitat than the habitat they have spawn?

3.4 LOTIC COMMUNITIES

Lotic aquatic systems are those systems which contain flowing waters. For instance; springs, streams, and rivers are familiar examples of lotic systems. The primary function of these lotic bodies of water is to carry the surplus rain water back to the sea. Lotic water system exhibits longitudinal zonation or profile instead of horizontal as seen in lakes and ponds discussed in the previous sections. In 1963, Lilies and Botosaneanu have recognized two major subdivisions of a stream/river course.

1. **Rhithron**: The steep and torrential upper course known as rhithron. 'Rhithron' zone tend to exhibit an alternation between two zones:
   - **(a) Rapid Zone:** steep, narrow and shallow riffles or rapids- Riffles exhibits very high turbulent flow, coarse bottoms of boulders, rocks or pebbles as well as limited attached vegetation.
   - **(b) Pool Zone:** flatter, wider and deeper reaches are termed as pools. Pools exhibits lower flow, bottoms of finer material as well as some rooted vegetation. Pools show turbulent flow besides comparatively low temperatures.
2. **Potamon**- The flat, slow-flowing, lower course is known as potamon.. Zonation within the potamon is both longitudinal as well as lateral:
   - (a) Longitudinally, there is a repetition of different habitats associated with the meanders of the channel.
   - (b) Laterally, there is the distinction between the main channel and its floodplain.

The Characteristic features of a lotic system can be summarized as follows:

- There is a continuous unidirectional flow of water in a lotic water system.
- Stagnation is entirely absent.
- It contains water derived from diverse sources.
- The water levels in a lotic water system also exhibit a wide range of fluctuations.
- The volume of water keeps on changing in the lotic system which in turn brings about changes in the velocity of water currents.
- Water in a lotic system helps in the transfer, transport, as well as dilution of materials all along their channels.
- Contents or materials are mixed thoroughly in a lotic aquatic system.
- Physio-chemical properties of water are always in a state of continuous change.
- Plenty of oxygen is derived from the atmosphere, i.e., air present above the water mass.
- Further, more oxygen is produced by autotrophs.
- Turbidity of the water in lotic system usually limits light penetration to deeper zones of lotic systems.
- Large crops of algae and other organisms rarely develop in moving waters.

- Area and depth show little correlation with productivity in lotic waters.
- Presence of water current is the leading feature of a lotic system. Biological productivity is often found to be low in rapidly flowing waters when compared to standing ones as seen in lentic water system. Further, the biological productivity of the lotic water system keeps on rising proportionately as the velocity of flow slows down. Organisms residing in lotic water system take full advantage of water currents to disseminate/spread their seeds, spores and other reproductive structures all along the length and breadth of the channel. Similar species may be found through the entire course of a lotic water system.

The biota associated with lotic water system are as follows:

(1) Bacteria

Bacteria are present in all regions of lotic waters. Free-living bacterial forms are associated with decomposing organic material, or are present on the surfaces of rocks as well as plants, suspended in the water column, and in the sediments of the benthic and profundal zones. A few other bacterial forms are associated with guts of lentic animals as parasites or in commensal relationships. Bacteria play an essential function in system metabolism via nutrient recycling. Majority of bacteria in lotic water system depends upon dead and decaying organic matter to obtain their energy. These bacteria are then eaten up by protozoa which in turn are consumed by zooplankton and then further up the trophic levels.

(2) Primary Producers

Algae, comprised of phytoplankton and periphyton, are the major primary producers in most streams and rivers (Giller and Malmqvist 1998). Phytoplankton float freely in the water column however they are unable to maintain high populations in fast flowing streams. Phytoplankton population can rise steadily in slow moving rivers and backwaters (Allan 1995). Periphyton are typically filamentous in structure and remain attached to the objects to avoid being washed away by fast river/ stream current. In slow moving rivers/streams, periphyton may form a gelatinous, unanchored floating mat (Cushing and Allan 2001).

Like phytoplankton and periphyton, plants also show limited adaptations to fast current and thus thrive only in slow moving waters. Primitive plants, like mosses and liverworts attach themselves to solid objects. Other plants like duckweed or water hyacinth floats freely at the water's surface. Rooted plants usually occur in areas of slackened current where fine-grained soils are found (Brown 1987; Cushing and Allan 2001). These rooted plants are flexible, with elongated leaves that offer minimal resistance to current (Angelier 2003).

Phytoplanktons, periphyton as well as plants are essential to lotic systems and serve as food source, sources of energy, microhabitats for several animals etc.

(3) Insects and Other Invertebrates

Approximately, 90% of invertebrates in lotic systems comprises of insects. Most commonly found insects in the lotic system include molluscs such as; snails, limpets, clams, mussels, as well as crustaceans like crayfish and crabs. They are present at places like surfaces of stones, deep below the substratum, adrift in the current, and in the surface film. These insects have developed numerous adaptations to thrive well in the lotic system:

(a) Avoiding high currents.

(b) Inhabiting the substratum or the sheltered side of rocks.

(c) In case of strong river/stream current, insect species have developed weighted cases or have pads of silk for anchorage or suction cup like devices.

(d) Presence of streamlined bodies.

(4) Fish and Other Vertebrates

Fishes are perhaps the best-known inhabitants of lotic water system. The capability of a fish species to thrive in flowing waters depends upon the speed at which it can swim as well as the duration for which it can maintain a particular speed. Swimming requires a lot of energy and hence fishes only spend a short period in full current either to feed or change locations. Instead, they prefer to stay close to the bottom or the banks, behind obstacles or sheltered from the current. Few fish species are completely benthic and never venture into the open water flow. Fishes exhibit several adaptations to survive in the water flow like dorso-ventrally flattened body, streamline body structure, eyes on top, lateral line system, etc.

Lotic systems typically connect to each other, forming a path to the ocean, i.e., spring $\rightarrow$ stream $\rightarrow$ river $\rightarrow$ ocean, and several fish species have life cycles that require stages both in fresh as well as salt water. For example Anadromous fish is born in freshwater, spends most of its life in seawater and then, returns to freshwater to spawn whereas Catadromous fish is born in seawater, spends most of its life in freshwater and then, returns to seawater to spawn. Anadromous and catadromous fish are two types of fish who live in a separate habitat than the habitat they have spawn. Salmon, smelt, striped bass, shad, and sturgeon are examples of anadromous fish while eels are an example of catadromous fish. Other vertebrate taxa that inhabit lotic systems include amphibians, such as salamanders, reptiles (e.g. snakes, turtles, crocodiles, and alligators), various bird species, and mammals (e.g. otters, beavers, hippos, and river dolphins).

3.4.1 Biotic Communities Present in River/Streams

Streams are zones where a quick flow of shallow water creates a shearing stress on the stream bed, leading to a rocky or gravel substratum covered by fully oxygenated water. A stream can be defined as a body of water with a current and is smaller than a river. When merged, they can form a bigger body of water either flowing or nonflowing water ecosystem (like lakes, river, etc.). The size of the stream may vary from tiny rivulet to rivers. Streams are abundantly present in areas of abundant rain fall. Streams can be temporary or permanent. Streams are closely associated to their watersheds. The productivity of streams is regularly dependent on terrestrial bases, grasses, as well as other debris. Streams are divided into two zones as explained in previous section.

Biotic communities of the rhithron zone comprises of plankton, periphyton, aufwuchs, nekton as well as benthos. They are described as follows:

(1) Phytoplankton: These are the major primary producers in the 'Rhithron' zone. Phytoplankton are small microscopic, unicellular, and photosynthetic organisms which freely float in water bodies. Phytoplankton composed of both eukaryotic as well as prokaryotic species which colonizes upper euphotic part of the water column. In rhithron zone of comparatively undisturbed stream, the major primary producers are the filamentous green algae like *Ulothrix* and *Cladophora*, and diatoms like *Nizschia* and *Gomphonema*. Ulothrix belongs to the class *Chlorophyceae*. They are usually green due to the presence of pigments like chlorophyll a, chlorophyll b, and beta-carotene. Pigments are present in plastids or chromatophores. Starch is the main photosynthetic food product. In chromatophores, pyrenoids are present. Both flagella are equal in length, i.e., they are isokonate. Cell wall is made up of cellulose. Diatoms are members of the class *Bacillariophyceae* (division *Chromophyta*), with approximately 16,000 species found in sediments or attached to solid substances in aquatic bodies. The markings of cell wall, structure and position of raphae and nodules are the distinguishing features for identification of species. The diatom cell is well known as frustules and typical feature is possession of silica cell wall. This structure is extremely ornamental, which is species specific and frequently used as means of identification. Diatoms are among the most significant and productive microscopic sea organisms and serve directly or indirectly as food for many animals.

(2) Aufwuchs: Those organisms that attach firmly to a substrate (submerged rocks, plants, debris) but do not penetrate it (in contrast to plants rooted in the bottom or certain parasites) are collectively called known as 'Aufwuchs'. In fresh water insects larvae,molluscs, oligochaetes and tardigrades are part of fresh water aufwuchs fauna.

(3) Zooplankton: The zooplankton of the 'Rhithron Zone' majorly comprises of ciliate protozoans (*Vorticella*), Rotifers (*Asplancha, Brachionus, Keratella, Philodina*), and crustaceans (*Daphnia, Bosmina, Cyclops, Diaptomus, Gammarus pulex,* etc.).

Commonly Found Insects in Streams

(a) Mayflies belongs to the insect order Ephemeroptera (*Rhithrogena, Ameletus, Caenis, Baetis rhodani, Ephemerella, Ecdyonurus, Epeorus,* etc.).

(b) Stoneflies belonging to the order Plecoptera (*Protonemura, Leuctra, Diura, Brachypterd Nemoura, Perlodes, Arcynopteryx, Perla, Isoperla,* etc.).

(c) Caddisflies belonging to the order Trichoptera (*Rhyacophila, Philopotamus, Hydropsyche, Drusus, Agraylea, Limnephilus,* etc.).

(d) Insects belonging to the order Diptera (*Chironomus riparius, Simulium,* etc.)

(e) Dragonflies belonging to the order Odonata (*Libellula*).

NOTES

Benthic Organism in Streams

Benthic organisms are present on the sea bed that are sessile, burrowing, creeping, etc. Some worms are commonly present in streams (flatworm (*Dugesia)*, roundworm (*Dolichodorus)*, annelid worm (*Tubifex*), leeches (*Glossiphonia, Haemopis, Erpobdella*), molluscus (*Dreissena, Bithynia*,), and crustacea (*Gammarus*) may also occur among the benthic forms.

Nektons Present in Streams

The term nekton is used for actively swimming organisms. Nekton community residing in streams comprises of water bugs belonging to the insect order Hemiptera (*Micronecta, Gerris, Notonecta, Corixa*), beetles belonging to the order Coleoptera (*Dytiscus*) and fish. Fish species residing in rhithron zones belongs to two categories:

(a) Small size fish species which live among rocks of the bottom and are adapted to grip or cling to the substrate. (*Pseudecheneis, Astroblephus, Chiloglanis, Glyptothorax*).

(b) These fish species are adapted to swim fast as to resist the water current or even swim against it. (*Salmo, Barbus, Schizothorax, Barilius*, *Tor*).

The common adaptation seen in biotic Communities residing in Rhithron zone are as follows:

(a) Streamlined Bodies

Streamlined shaped bodies of animals' offers minimum resistance to water flowing over it, as seen in *Salmo, Barilius,* and *Schizothorax* species.

(b) Flattened Bodies

Flatted bodies helps animals to find shelter under stones. As seen in fishes like Noemacheilus (Cobitidae) and Pseudecheneis (Sisoridae).

(c) Hooks and Suckers

Hooks and sucker helps animals to have a strong grip on smooth surfaces. As seen in; Bibicocephala and Liponeura possess a row of ventral suckers.

(d) Adhesive Apparatus

Presence of well-developed adhesive structures on ventral surface for firm grip. As seen in fishes like; *Glyptothorax, Garra, and Pseudecheneis*.

(e) Sticky Under-surfaces

Sticky under-surfaces present in few snails and flatworms also serve the adhesive purpose.

(f) Positive Rheotaxis

This adaptation helps the animal to orient themselves upstream or swim against the water current.

(g) Positive Thigmotaxis

This adaptation exhibited by larvae of insects (mayflies and stoneflies) helps the animal to cling close to a surface or to keep the body in close contact with the substratum.

(h) Permanent Attachment

A few organism remain attached permanently to a firm substrate like stone, log, or leaf mass. As in phytoplankton such as green algae (*Cladophora*), diatoms (*Nitzschia, Gomphonema, Melosira)* and few aquatic mosses (*Fontinalis*).

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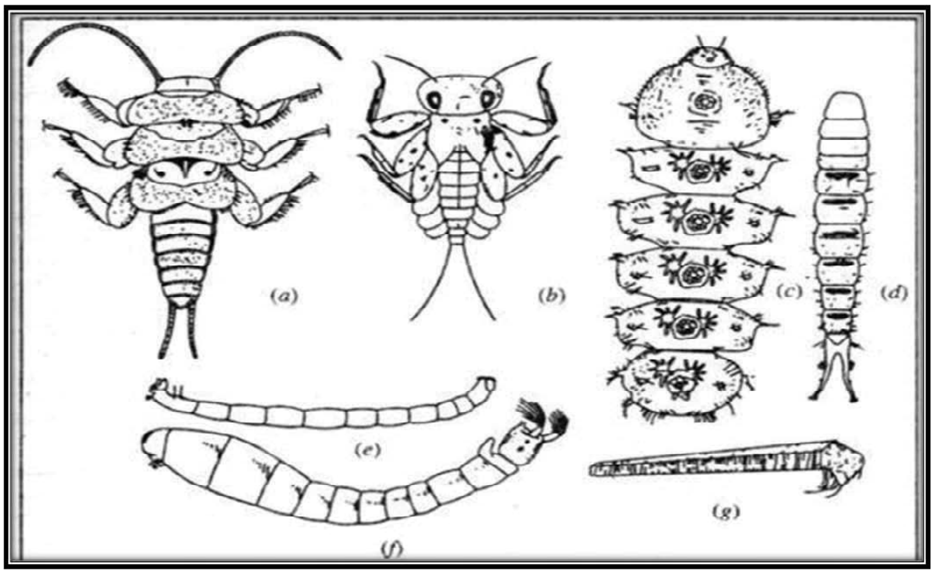

Fig. 3.11 *Adaptations/Modification in Lotic Communities.*

Figure 3.11 is depicting the adaptations/modification in lotic communities.

a*)* Stonefly nymph; b) Mayfly nymph; c) Blepharocera; d) Antocha e) Chironomus; f) Simulium; g) Caddisfly larva

Source of figure: Needham and Needham, 1972, A Guide to Study of Freshwater Biology

The biotic communities of potamon zone are as follows:

(1) Plankton

The presence of plankton is associated with the flow conditions. During floods, rare planktonic organisms may be present however during dry seasons algal blooms may develop within the lentic waters of the plain as well as in the main channel. In short rivers, these are usually confined to backwaters whereas in extended rivers the time taken for specific masses of water to travel downstream is enough to let the development of plankton.

(a) Algae and Diatoms

Algae and Diatoms are the most common phytoplankton present in potamon zone of streams. The type of algal species growing in potamon zone depends upon its tolerance to pollution. For instance, algal species like *Euglena viridis, Scenedesmus quadricauda, Microcystis, Oscillatoria limosa, Ankistrodesmus falcatus, Phacus caudatus, Navicula viridula, Stigeoclonium tenue, Chlorella vulgaris, Synedra ulna and P. viridis* are regularly limited to the sites of urban and industrial discharge. However, algal species like *Anabaena circularis, Gomphonema parvulum, Phormidium uncinatum, Pediastrum duplex,* *Cymbella turgida, Oscillatoria princeps, Scenedesmus dimorphus, Closterium acerosum, Synedra acus, Navicula cuspidate* are pre-dominantly present in clean or moderately polluted zones.

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Further, algal species like *Oscillatoria subbrevis, Melosira ambiguans, Pediastrum simplex, Phormidium calcicole, Merismopedia glauca, Gomphonmea species* are present in highly clean water.

(b) Zooplankton

Zooplankton members of the potamon zone comprises of members like copepoda, protozoa, rotifera Cladocera. Further, species like *B. quadridentate, B. forficula, B .calyciflorus, Filinia longiseta, K.cochlearis, Brachionus angularis, Keratella tropica* are present in both clean as well as moderately polluted waters. However, species like *Rotatoria rotatoria Platiyas polyacanthus Brachionus rubens* are representative of polluted parts of the potamon zone.

(2) Nekton

The term nekton is used for actively swimming organisms. A few insects like beetles and fish are pre-dominantly present in the potamon zone.

Potaman zone serves as a habitat to two major group of fish communities. Firstly, there are fish species which are highly adapted to resisting low dissolved oxygen concentration. For example *Notopterus, Erythrinus, Clarias, Channa,* etc. Other group of fish species which habitats the main channel are *Labeo species, Catla catla, Mystus (Aorichthys) species* and *Cirrhinus mrigala*.

(3) Benthos

Benthic organisms are sessile, burrowing, creeping animals that are present on the sea bed. Condition of the potamon zone like heavy siltation, seasonal desiccation as well as unstable mud bottoms are not favourable for bottom living organisms. Some of the benthic forms present in potamon zone are molluscs (like *Corbiula, Lymnaea* and *Bithynia*) as well as certain worms and leeches.

(4) Macrophytes

The presence of macrophytes is a distinguishing feature of the potamon zone. The free-floating macrophytes like *Eichhornia crassipes* (water cabbage), *Salvinia,* (water fern) and *Pistia* (water lettuce) are most commonly observed macrophytes in potamon zone. Rooted macrophytes either completely submerged or having a part of their vegetative or sexually reproductive parts exposed like *Myriophyllum* (milfoil), *Potamogeton (*pond weed), *Ceratophyllum* (coontail) and *Nymphaea* (waterlily) are commonly found in potamon zone.

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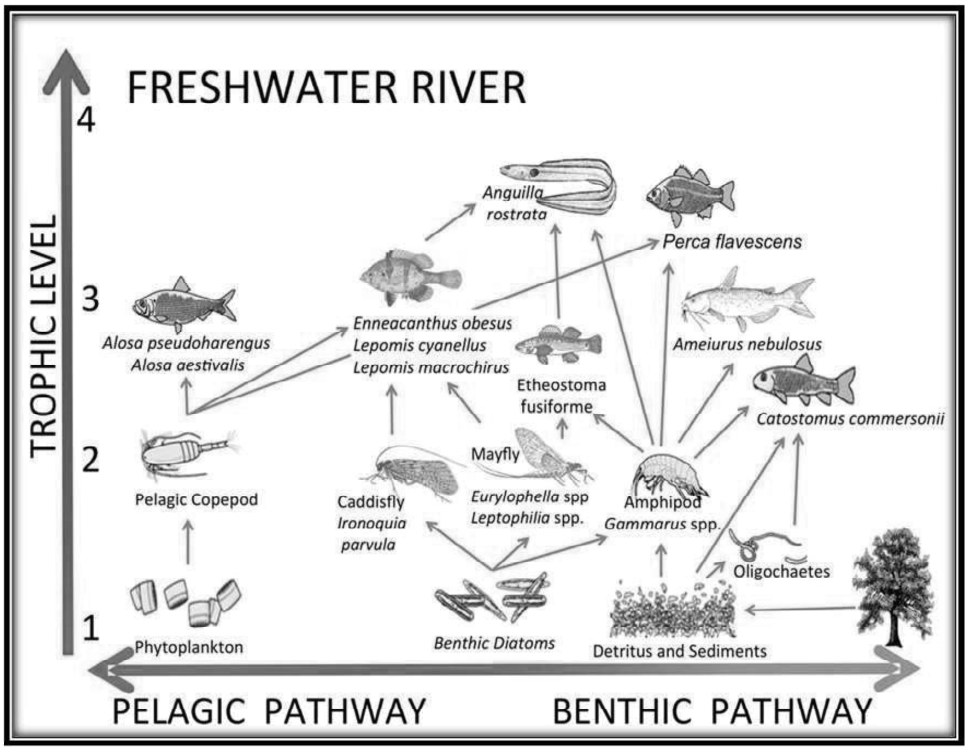

Fig. 3.12 *Food-Web in a Freshwater River*

Figure 3.12 depicts the Food-Web in a freshwater river.

3.5 PLANKTON

The term plankton was first proposed by an Oceanographer, Victor Hensen in 1887. The term 'Plankton' collectively refers to all the organisms present in marine as well as freshwater system. Planktons are non-motile organisms that cannot swim against the water current. They are drifted by water currents. A few general features of planktons are as follows:

- The size of the Planktons varies widely from 0.2 mm to more than 20 cm.
- Horizontal and vertical distribution of the planktonic organisms within the aquatic system depends upon a lot of biotic and abiotic factors.
- Planktons acts as food source for large aquatic organisms.
- Planktons have a huge ecological role to play in the ecosystem. For instance, phytoplankton account for 50% of the total oxygen (O_2) produced via the process of photosynthesis.

Planktons differs from other aquatic species, for example

Pleuston – Pleuston refers to floating organisms.

Nekton –The term nekton is used for actively swimming organisms.

Neuston – Neuston refers to organisms that are present on the water surface.

Benthos – Benthic organisms are present on the sea bed that are sessile, burrowing, creeping, etc.

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3.5.1 Classification of Plankton

Planktons are categorised on the basis of lifecycle, size and trophic level.

(1) The classification of planktons based on the lifecycle (planktonic life) is as follows:

- **Holoplankton**: Holoplankton refers to the organisms that remain in planktonic form for their entire lifetime, For instance; algae, jellyfish, etc.
- **Meroplankton**: Meroplankton refers to the organisms, who live as planktonic organism only at some stages of their lifecycle, for instance; larvae of starfish, worms, sea urchins, fish, etc.

(2) The classification of the planktons based on size is as follows:

- **Megaplankton**: Megaplankton are large in size > 20 cm (20-200 cm). Metazooplankton are found in this category. For example Jellyfish, siphonophores, scyphozoan, pelagic tunicates, chain forming scalps, etc. Figure is depicting the megaplankton.

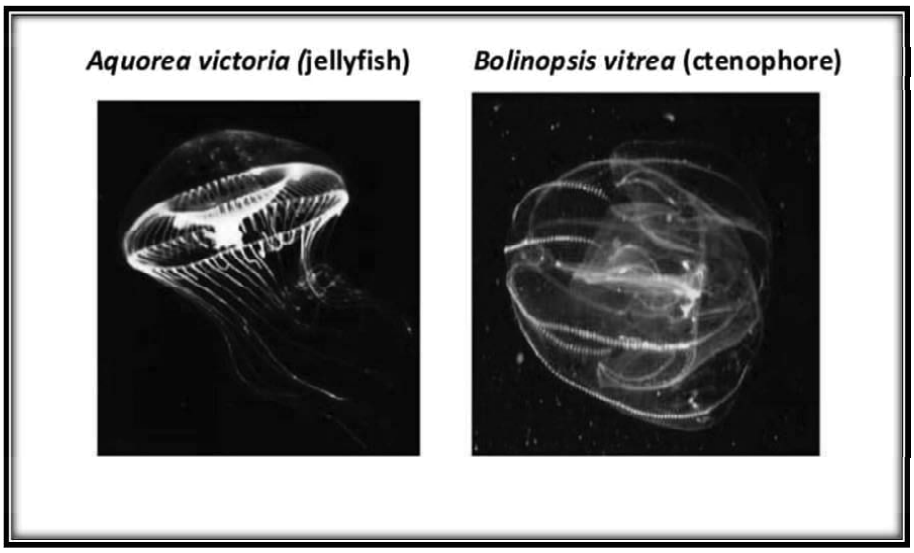

Fig. 3.13 *Megaplankton*

- **Macroplankton**: The size of the Macroplankton varies from 2mm to 20 cm. Phytoplankton, Protozooplankton, and Metazooplankton belongs to this specific category. For example larger specimens of hydromedusae, siphonophores, scyphomedusae, ctenophores, mysids, amphipods, euphausiids, salps, eel larvae, etc. Figure 3.14 is depicting the macroplankton.

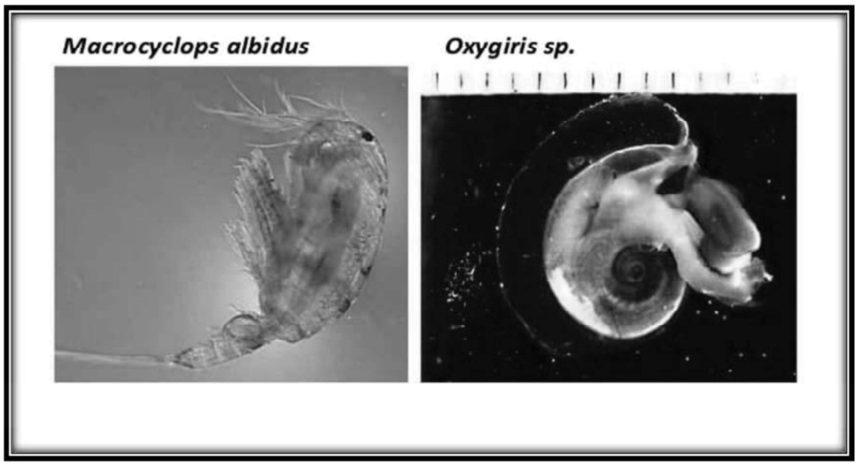

Fig. 3.14 Macroplankton

- **Mesoplankton** –Mesoplankton has a size range of 0.2 mm to 2 mm. Phytoplankton, Protozooplankton, Metazooplankton belongs to this specific category. For example Small Hydro Medusae, Ctenophores, Chaetognaths, Appendicularians, Doliolids, fish eggs and larvae together with older stages of crustacean plankton and meroplanktonic larva. Figure 3.15 is depicting the mesoplankton.

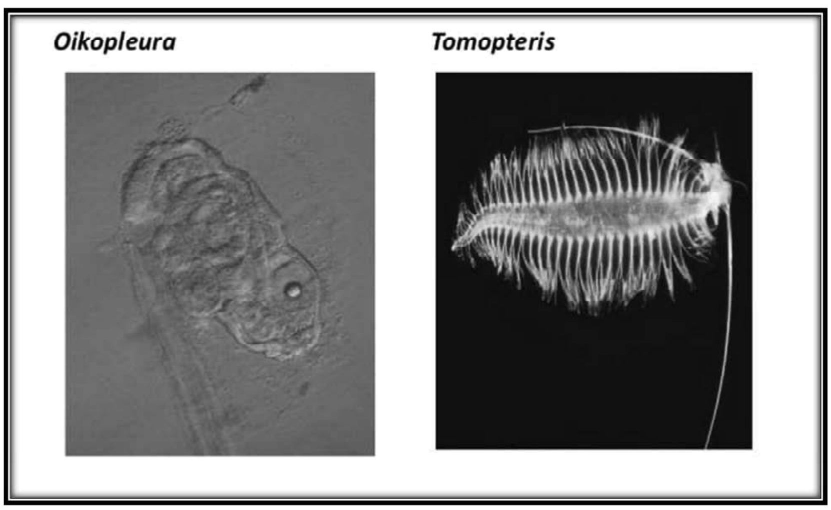

Fig. 3.15 Mesoplankton

- **Microplankton**: The size of the microplankton varies from 20 to 200 mm. Myco-plankton, Phytoplankton, Protozooplankton, Metazooplankton belongs to this specific category. For example most protozoans especially ciliates, eggs, and early larval stages of crustacean plankton and meroplanktonic larvae. Figure 3.16 is depicting the microplankton.

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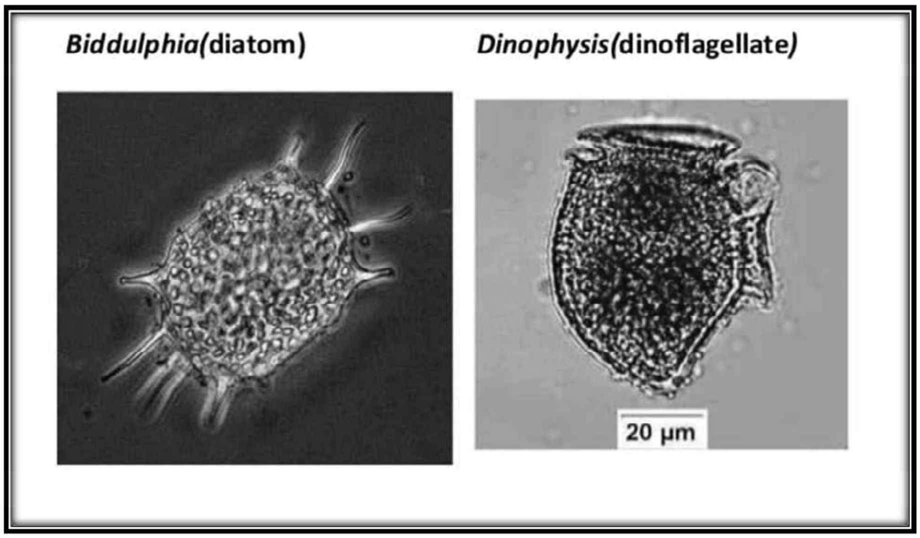

***Fig. 3.16** Microplankton*

- **Nanoplankton**: The size of the nanoplankton ranges from 2 to 20 mm, e.g. protists, diatoms and algae. Bacterio-plankton, Myco-plankton, Phytoplankton, Protozooplankton belongs to this specific category. For example heterotrophic nano flagellates feeding on bacteria
- **Picoplankton**: The size range for picoplankton varies from 0.2 to 2 mm, e.g. bacteria, chrysophytes.
- **Femtoplankton**: Femtoplankton includes marine viruses with size < 0.2 mm.

(3) The classification of the planktons based on various trophic level and characteristics is as follows:

- **Phytoplankton** – Phytoplankton are autotrophs or producers, e.g. algae, cyanobacteria, dinoflagellates, diatoms, etc.
- **Zooplankton**: Zooplankton includes primary consumers, i.e., those planktonic organism who feed on other plankton, e.g. larvae of fish, small protozoans, as well as other animals.
- **Mycoplankton**: Mycoplankton includes fungi.
- **Bacterioplankton**: Bacterioplankton includes bacteria essential for nutrient recycling.
- **Virioplankton**: Virioplankton includes viruses.
- **Mixotrophs**: Mixotrophs act as both producers and consumers according to environmental conditions. In the presence of abundant light and nutrients they perform the process of photosynthesis while in the absence of these resources they feast on other planktonic organisms to fulfil their nutritional requirements.

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The classification of planktons based on local environmental distribution is as follows:

- **Limnoplankton**: They are called as lake plankton.
- **Rheoplankton (Potamoplankton**): they are known as running water plankton. **Heleoplankton:** They are known as pond plankton.
- **Haliplankton**: They are known as salt water plankton.
- **Hypalmyroplankton:** They are known as brackish water plankton.

The classification of planktons based on origin is as follows:

- **Autogenic Plankton**: They are the plankton which are produced locally.
- **Allogenic Plankton**: They are the plankton which are introduced from other localities.

The classification of planktons based on content is as follows:

- **Euplankton / True plankton**: They are true planktons.
- **Pseudoplankton (False plankton)**: They are debris mingled in plankton.

The classification of planktons based on habitat in water body is as follows:

- **Hypoplankton:** These are benthic planktons.
- **Epiplankton:** These planktons are present on the surface of the aquatic body.
- **Bathyplankton:** These planktons are present in aphotic zone.
- **Mesoplankton:** These planktons are present in the disphotic/lighted zone.

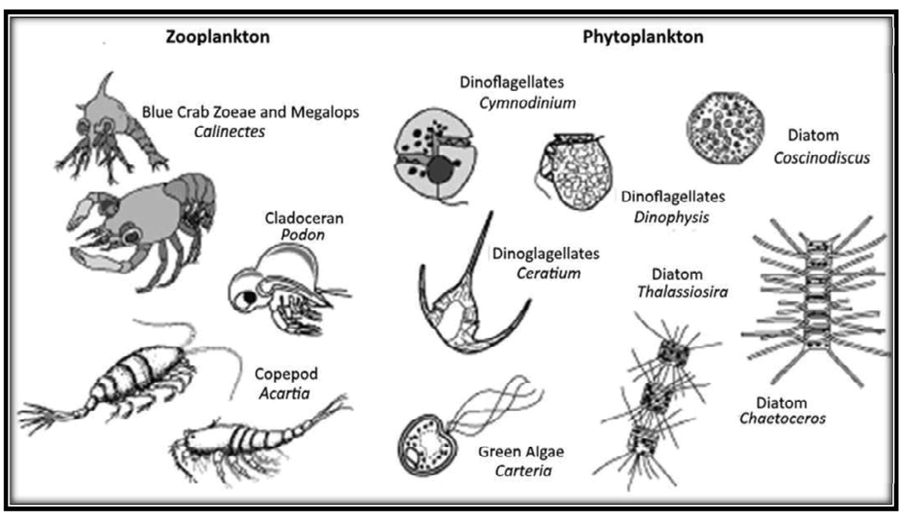

Fig. 3.17 *Phytoplankton and Zooplankton*

Figure 3.17 is depicting phytoplankton and zooplankton.

3.5.2 Distribution of Plankton

Planktons are widespread in aquatic bodies irrespective of latitude, longitude, and physic-chemical characters. Planktons can also be observed in thermal waters, spring-fed streams, subterranean waters, transient pools etc.

General Geographical Distribution of Plankton

Oceanographers claims that the polar seas support abundant plankton than tropical ones.

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Horizontal Distribution of Plankton:

The horizontal distribution of planktons is highly irregular in the water. The prime reason being wind acting on water surface. Since, wind causes waves, however, additionally it may produce an actual drift of the upper waters. Moreover, under certain conditions of drifting water, planktonic organisms become more and more concentrated temporarily in the vicinity of the shore which faces into the wind at that time.

Other significant factors which are responsible for horizontal distribution of the plankton in the water are as follows:

(a) inflowing streams

(b) irregularity of shore line

(c) depth of water

(d) flowage areas

(e) water current, etc.

Vertical Distribution of Plankton

The vertical distribution of plankton is a complex matter as in deeper aquatic regions plankton may show little or no resemblance to that of upper waters. The factors responsible for vertical distribution of plankton are as follows:

(a) **Light**: Light is the prime factor governing the vertical distribution of plankton. The annual and diurnal variation of light, qualitative and quantitative variation influence the migration of plankton. Further, differences in reaction to light stimulus affects the vertical distribution of the different life history stages in the same species.

(b) **Food**: The distribution of different types of zooplanktons depends upon the distribution of food in the water.

(c) **Dissolved gasses and other substances**: Chemical variations in water at the bottom creates unfavourable circumstances for plankton. Deep water becomes moderately or completely uninhabitable for most plankton if there is a lack of dissolved oxygen, even if supplementary elements are appropriately present. The breakdown effects of organic matter on the bottom of the water tend to be more sensitive to certain plankton as compared to others. However, not all upper plankton die as a result of certain stratification. Moreover, chemical deviations tend to be deadly for most or all types of plankton in maximum cases. Consequently, plankton ultimately became extinct from some of the lower layers.

(d) **Temperature**: Temperature directly or indirectly affects the vertical distribution of plankton as follows:

   (i) Selection of some optimal temperature by some moving plankton.

   (ii) Failure of certain immobile plankton to settle down at certain temperature levels.

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Vertical distribution can easily be observed in plankton that are sensitive to temperature differences. However, most plankton are not affected by vertical temperature difference in a lake. The thermal properties of the thermocline layer are considered to be an excellent quality measure in defining the position of certain plankton. Temperature also indirectly influences changes in density as well as viscosity. Such variations modify the floating level of the adaptive plankton so as to float smoothly. Moreover, it is believed that such circumstances indirectly play a part in altering the light sensitivity of the lymphatic crustacean. Increases sensitivity at higher temperatures and decreases sensitivity at lower temperatures leading to creation of different levels of reactions.

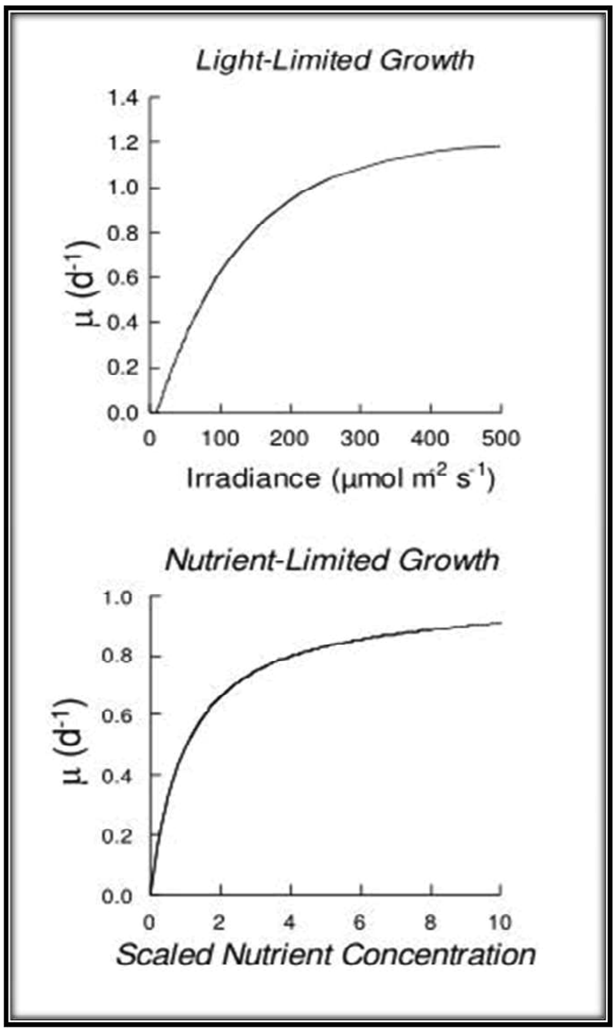

Fig. 3.18 *Growth Rate of Phytoplankton with Light*

Temperature and Presence of Nutrients

Figure Graph depicts the growth rate of phytoplankton depends on light, temperature as well as presence of nutrients in the aquatic system

(e) **Wind**: The effect of wind varies with the season.

(f) **Gravity**: Reduction of specific gravity makes certain phytoplankton such as, Gloeotrichia to congregate at the surface waters. Further, planktons like pelagic crustacean are heavier than water and tends to sink with appreciable speed when inactive.

(g) **Age of Individual of a Species**: In general, young individuals appear near surface whereas adults tend to sink into deeper waters.

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Food for Plankton Organisms

The food requirement of plankton is highly diverse as described below:

a. **Green Phytoplankton:** Green phytoplankton contains chlorophyll and utilises organic and inorganic materials dissolved in water.

b. **Non Green Phytoplankton:** Non green phytoplankton do not possess chlorophyll, such as bacteria depend upon dissolved materials.

c. **Protozoa:** They feed upon minute algae and bacteria. Utilisation of dissolved substances has been demonstrated in certain protozoa.

d. **Metazoan:** In 1929, Neumann considered the relation of zooplankton as seston feeders into the 4 types namely:

   a. Grasping type: They touch and secure seston with the help of pseudopodia like Rhizopoda

   b. Filtration type: It involves filtering of seston from water as animal moves.

   c. Sedimentation type: It involves capturing of seston via inducing water currents

   d. Predatory type: They capture other organisms.

   e. **Cladocera:** They obtain their food by active filtration of water as well as by predation. Cladocerans filter their food which includes particulate matter such as inorganic debris, organic debris, and living organisms from water.

(6) **Copepods:** Digestive tracts of Copepods reveals that:

(a) Cyclops had fragments of exoskeleton of Entomostraca, jaws of rotifers

(b) Nauplii had eaten finely granular mass for minute algae.

3.5.3 Ecological Significance and Importance of Plankton

Planktons have huge ecological significance.

- Phytoplankton acts as producers of the aquatic system and accounts for approximately half of the total amount of oxygen evolved during the process of photosynthesis.
- Fisheries are dependent on plankton up to major extent for fish food.
- Phytoplankton acts as a source of food in space travel and also for carbon dioxide fixation.
- Chlorella is used as a protein supplement.
- They play significant role in nutrient recycling. Dead and decaying organic matter can be transformed into inorganic nutrients for plants.

- Some phytoplankton can fix nitrogen and can grow in areas where nitrate concentrations are low.
- Phytoplankton as well as zooplankton are vital for maintaining carbon dioxide and oxygen balance.
- CO_2 uptake of an oceanic body can be increased by phytoplanktonic growth.
- Bioluminescent planktons are accountable for a blue flash of light in the sea.
- Unicellular dinoflagellates multiply at a rapid rate leading to a bloom in the presence of abundant nutrients. They produce toxins and are harmful for fish and other organisms feeding on fishes. They are also known to cause red tide.

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Check Your Progress

9. What is the primary function of lotic bodies of water?
10. Why the fish are the best-known inhabitants of lotic water system?
11. Define streams.
12. What is the difference between holoplankton and meroplankton?
13. How the temperature does affects the vertical distribution of plankton?

3.6 PHYTOPLANKTON

Phytoplankton are small microscopic, unicellular and photosynthetic organisms which freely float in water bodies. Phytoplankton composed of both eukaryotic as well as prokaryotic species which colonizes upper euphotic part of the water column ranging from freshwater to ocean conditions. They also exhibit amazing adaptation to remain in floating condition. The range of the Phytoplankton cells can vary in size from about 1 mm to 1 mm. Like terrestrial plants, these tiny primary producers need sunlight, nutrients as well as carbon dioxide for their growth and multiplication. Phytoplankton cells contains chlorophyll which helps them to synthesize food in the presence of sunlight. Therefore, they help in maintaining not only the carbon dioxide level but also help to alleviate global warming to some extent. Physical process like wind and water current play substantial part in their distribution particularly in estuarine and marine conditions. Phytoplankton act as primary link in energy pathway to higher trophic level via several food chains. Phytoplankton supports nearly half of global primary production which directly or indirectly supports almost all marine life. Phytoplankton are a chief food source for diverse range of organisms like zooplanktons, larvae, and juveniles of fishes as well as some invertebrates. The annual cycle of the phytoplankton remains predictable throughout the year, however, occasionally some species may develop exponentially leading to the formation of algal blooms.

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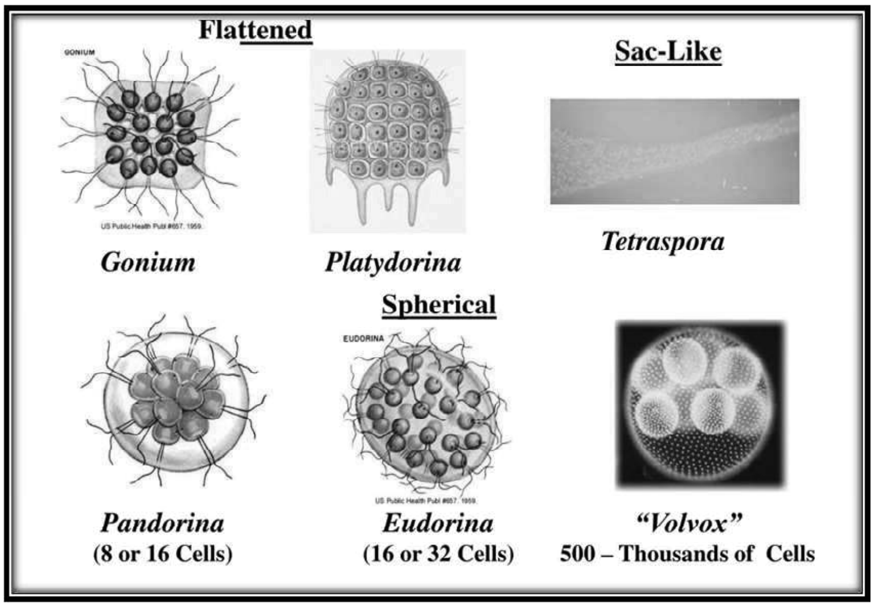

Fig. 3.19 *Phytoplankton*

Figure 3.19 is depicting the phytoplankton.

Phytoplankton can further be classified into different categories as explained below:

(1) Classification of phytoplankton on the basis of size:

- **(a) Microplankton:** Size range varies from 200-20 mm.
- **(b) Nanoplankton**: Size range varies from 20-2 mm.
- **(c) Picoplankton**: Size range varies from 2-0.2 mm.

2) Classification of Phytoplankton on the basis of colour (Proposed by W.H. Harvey in 1836):

- (a) **Chlorospermae**: They are green algae and fresh water forms.
- (b) **Melanospermae:** They are brown algae.
- (c) **Rhodospermae**: They are red algae.

(3) Classification of Phytoplankton based on pigment and morphological characters (Proposed by Fritsch 1935, 1945):

It is the most accepted classification globally and divides the phytoplankton into 11 classes:

(a) Chlorophyceae: They are usually green due to the presence of pigments like chlorophyll a, chlorophyll b, and beta-carotene. Pigments are present in plastids or chromatophores. Starch is photosynthetic food product, but rarely oil as in *Vaucheria*. In chromatophores pyrenoids are present. Both flagella are equal in length, i.e., they are isokonate. Majority of genera live in fresh water and few live-in marine waters. Cell wall is made up of of cellulose, eg, *Chlamydononas, Char, Vaucheria, Volvox, Cladophora, Stigiocloxeum, Ulothrix and Chlorena.*

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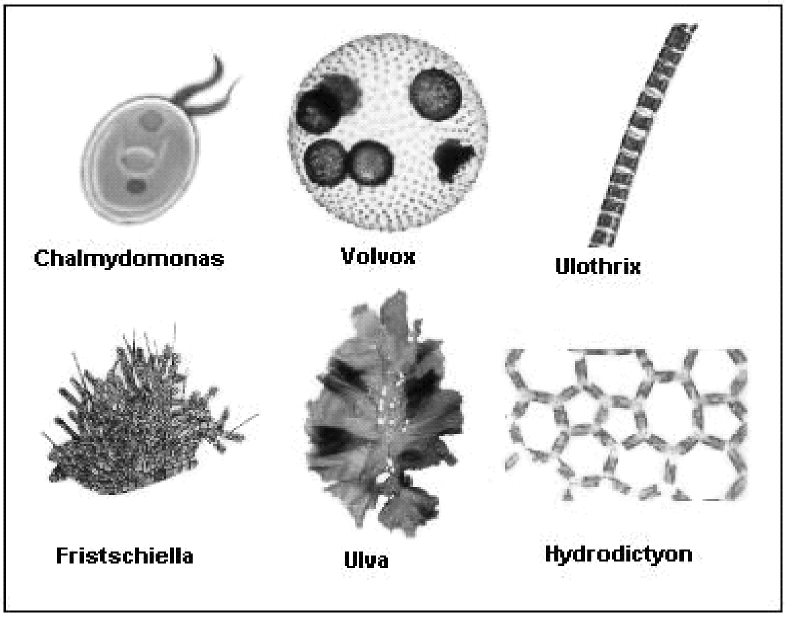

Fig. 3.20 Different Phytoplankton

Different phytoplankton shown in figure 3.20.

b) **Cryptophyceae**: The cryptophyceaens are phytoplanktons, most of which have plastids. The group have evolved a whole variety of light-absorbing pigments, known as phycobilins that are able to absorb wavelengths which are not accessible to other plants or algae, allowing them to live in a variety of different ecological niches. Figure 3.21 is depicting member of class Cryptophyceae

Fig.3.21 Member of Class Cryptophyceae

(c) **Phaeophyceae**: They are commonly known as brown algae. Brown algae are a group of algae belonging to class Phaeophyceae. They are named due to their colour, which varies from brown to olive green. They are frequently

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found in marine environments but rarer in fresh water system. There are approximately 1500 species of brown algae, which vary significantly in their size and shape. They are multicellular and the colour depends upon the ratio of chlorophyll and the pigment, fucoxanthin. Reserve food products are alcohols, mannitol, and lamixarine. Motile reproductive cells are pyriform with two laterally inserted flagella. For example *Fucus, Ectocarpus.* Figure 3.22 is depicting member of class Phaeophyceae.

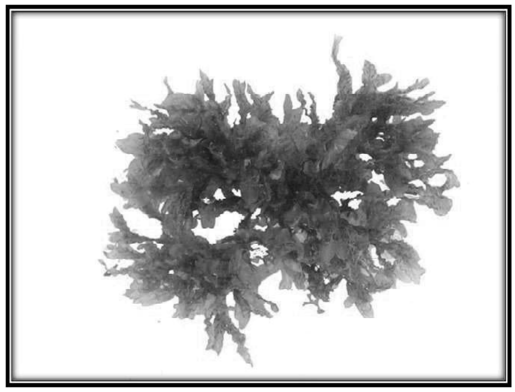

Fig. 3.22 *Member of Class Phaeophyceae*

(d) Rhodophyceae: They are commonly known as red algae due to the presence of a water soluble red pigment known as r- phycoerythrin. Reserve food material is polysaccharides starch and soluble sugar. They are non-motile, i.e., flagella are absent. They are frequently found in marine environments but fewer in fresh water system. Sexual reproduction is speciality and advanced. For example *Polysiphonia, Batrochospermum.* Figure 3.23 is depicting members of class Rhodophyceae.

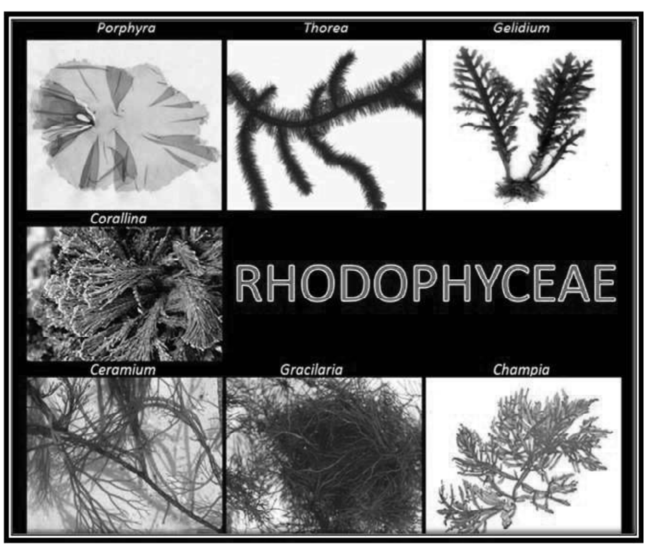

Fig. 3.23 *Members of Class Rhodophyceae*

(e) Xanthophyceae: Yellow-green algae or the xanthophyceae are an important group of heterokont algae. They are frequently found in fresh water environments but few are observed in marine water system as well as soil habitats. They vary from single-celled flagellates to simple colonial and filamentous forms. Xanthophyte chloroplasts contain the photosynthetic pigments chlorophyll a, chlorophyll c, â-carotene, and the carotenoid diadinoxanthin. Unlike other heterokonts, their chloroplasts do not contain fucoxanthin, which accounts for their lighter colour. They are called yellow green algae. Principal reserve is oil. Their biochemical features are shared by heterogenous assortment of species, the relationships between which are not close. For example *Vaucheria, Plumularia.* Figure 3.24 is depicting species of class Xanthophyceae.

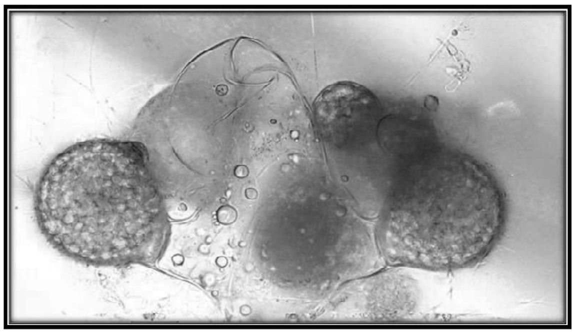

Fig. 3.24 *Species of Class Xanthophyceae*

(f) Dinophyceae: Dinoflagellates belongs to class dinophyceae. The dinoflagellates are single-celled eukaryotes constituting the phylum Dinoflagellata. Usually considered algae, dinoflagellates are mostly marine plankton, but they also are common in freshwater habitats. Their populations are distributed depending on sea surface temperature, salinity, or depth. They possess two flagella, one longitudinal while other in furrow and form significant blooms (known as red tides), which are often toxic. They have chlorophyll a, cholorophyll c, phycobilins, or fucoxanthin as main light harvesting pigments. Figure 3.25 is depicting the phytoplankton.

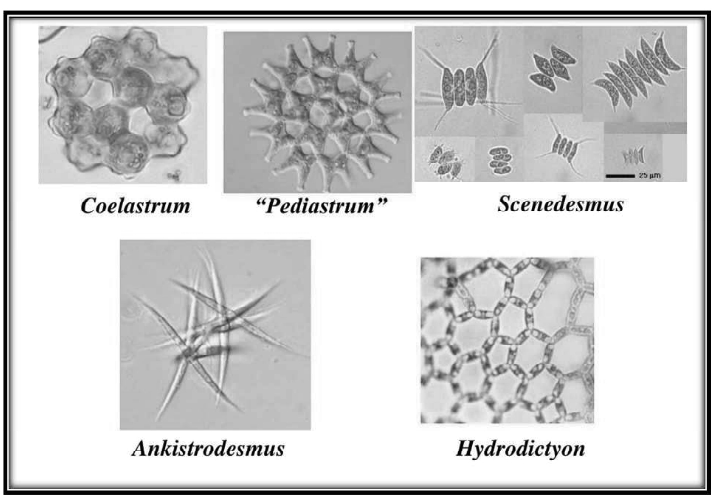

Fig. 3.25 *Phytoplankton*

(g) **Bacillariophyceae**- Diatom are members of the class Bacillariophyceae (division Chromophyta), with approximately 16,000 species found in

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sediments or attached to solid substances in aquatic bodies. The markings of cell wall, structure and position of raphae and nodules are the distinguishing features for identification of species. The diatom cell is well known as frustules and typical feature is possession of silica cell wall. This structure is extremely ornamental, which is species specific and frequently used as means of identification. Diatoms are among the most significant and productive microscopic sea organisms and serve directly or indirectly as food for many animals. Diatoms may be either unicellular or colonial. During reproduction, usually by cell division, the overlapping shell halves separate, and each secretes a (usually) smaller bottom half. Thus, individual diatoms formed from successive bottom halves show a progressive decrease in size with each division. In a few months there can be as much as a 60 percent decrease in average size. Periodic spore formation serves to restore the diatom line to its original size, e.g. diatoms.

(h) Chloromonadinae: They provide bright tint due to the presence of excessive of xanthophylls. Reserve food is generally fat or oil. Pyrenoids are absent. Two equal flagella are present. Sexual reproduction is absent, for example *Trentonia, Vacuolaria*.

(i) Eugleniae: These forms are found in freshwater, saltwater, marshes, as well as in moist soil. They are common in fresh water and are formed of a single cell. Body is highly elongated. Cell wall is absent. A thread or whip like flagellum is present for the purpose of locomotion. They are a group of flagellated micro-organisms. Many species have photosynthetic pigments similar to higher plants and are partly autotrophic in nature, such as *Euglena, Astrasia, Anisonema.* Figure 3.26 is depicting Euglena.

Fig. 3.26 *Euglena*

(j) Chrysophyceae: The Chrysophyceae, usually called chrysophytes, chrysomonads, golden-brown algae, or golden algae are a large group of algae, found mostly in freshwater. Chrysophytes contain the pigment fucoxanthin. They are called brown or orange Algae. Phycocheysin is dominant pigment which gives brown or orange colour to Algae plants. Chronatophore has naked pyrenoid bodies. Food reserve is chrysolaninarim and lencosin. Cell wall is cilified or calcified with no cellulose. There are two equal or unequal flagella. Sexual reproduction is rare, if present it is isogamous. For example *Chrysallonium, Chrysococcus, Chrysopsphaera.* Figure 3.27 is depicting species of class Chrysophyceae.

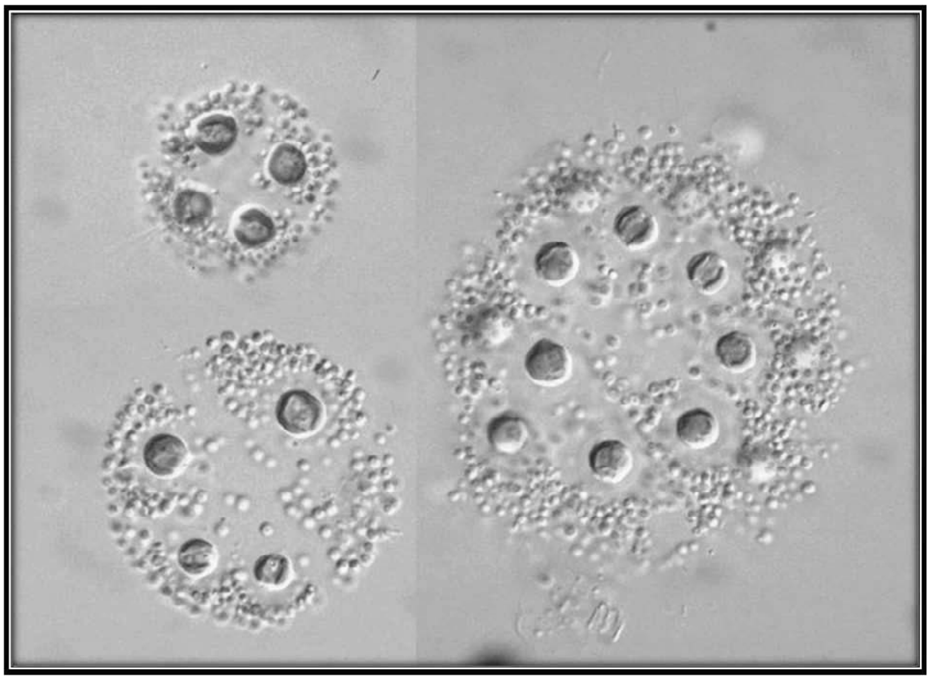

Fig. 3.27 *Species of Class Chrysophyceae*

(k) **Myxophyceae:** A primitive and simple type of cell structure. The presence of a blue pigment called c-phycocyanin and a red pigment (c-phycoerythrin) in addition to the usual photosynthetic pigments (chlorophyll a, carotenes, and xanthophylls) and these are not localized in the chromatophores but are distributed in the peripheral portion of the proto-plast known as chromoplasm. They are blue green algae. There are mostly fresh water as well as a few marine forms were also observed. Reserve food products are sugars and glycogen like compounds, cells of cynophecean contain starch. Flagella are absent. Sexual reproduction is unknown. Example *Oscillatoria, Nostoc,* etc.

3.7 ZOOPLANKTON

The name zooplankton is derived from the Greek words: *zoon*, animal; *planktos,* wandering. Zooplankters are microscopic, unicellular or multicellular forms with size ranging from a few microns to a millimetre or even more. Apart from size variations, zooplankters exhibit differences in morphological features as well as taxonomic positions consisting of representatives from almost every taxon of the animal kingdom. They are diverse, gentle, and beautiful groupings of animals that

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drift in the aquatic bodies and ads substantially to the faunal biodiversity of aquatic bodies. They play a significant role in the marine food web. They help in transferring organic energy obtained from unicellular algae to higher trophic levels like pelagic stocks. They act as food source for larval as well as juvenile fish, hence their reproductive cycles, growth as well as survival rates are essential factors influencing fishery. Zooplanktons can further be classified into different categories as explained below:

The classification of Zooplanktons based on the lifecycle (planktonic life) is as follows:

Holoplankton: Holoplankton refers to the organisms that remain in planktonic form for their entire lifetime, such as copepods, chaetognaths, salps, etc.

Meroplankton: Meroplankton refers to the organisms, who live as planktonic organism only at some stages of their lifecycle, such as larvae of starfish, worms, sea urchins, fish, etc.

The classification of Zooplanktons based on the size. (Described by Sieburth et al., 1978 and Harris et al., 2006)

Megaplankton: Megaplankton are large in size > 20 cm (20-200 cm). Metazooplankton are found in this category. Such as jellyfish, siphonophores, scyphozoan, pelagic tunicates, chain forming salps, etc.

Macroplankton: The size of the Macroplankton varies from 2 mm to 20 cm. Protozooplankton and Metazooplankton belongs to this specific category. Such as larger specimens of hydromedusae, siphonophores, scyphomedusae, ctenophores, mysids, amphipods, euphausiids, salps, eel larvae, etc.

Mesoplankton: Mesoplankton has a size range of 0.2 mm to 2 mm. Protozooplankton, Metazooplankton belongs to this specific category. For example small hydro Medusae, Ctenophores, Chaetognaths, Appendicularians, Doliolids, fish eggs and larvae together with older stages of crustacean plankton and meroplanktonic larva.

Microplankton: The size of the microplankton varies from 20 to 200 mm. Protozooplankton, Metazooplankton belongs to this specific category. For example, most protozoans especially ciliates, eggs and early larval stages of crustacean plankton and meroplanktonic larvae.

Nanoplankton: The size of the nanoplankton ranges from 2 to 20 mm, e.g. protists, diatoms and algae. Protozooplankton belongs to this specific category. For example heterotrophic nano-flagellates feeding on bacteria.

The classification of Zooplanktons on the basis of organization of the body is as follows:

Protozoa: Among the protozoan group, the ciliates form an ecologically important group. They rapidly multiply and are often the first grazers during algal blooms (diatom blooms).

Metazoa: Metazooplankton have comparatively longer life span ranging from several days, such as rotifers and few weeks, such as small crustaceans, to several years, such as large euphausiids in the Polar Regions.

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Zooplanktons are further classified into neritic and oceanic plankton.

Neritic- Neritic plankton inhabits inshore waters up to about 200 m depth.

Oceanic- sopelagic are the main domain of zooplankton. Figure 3.28 is depicting the zones in an ocean.

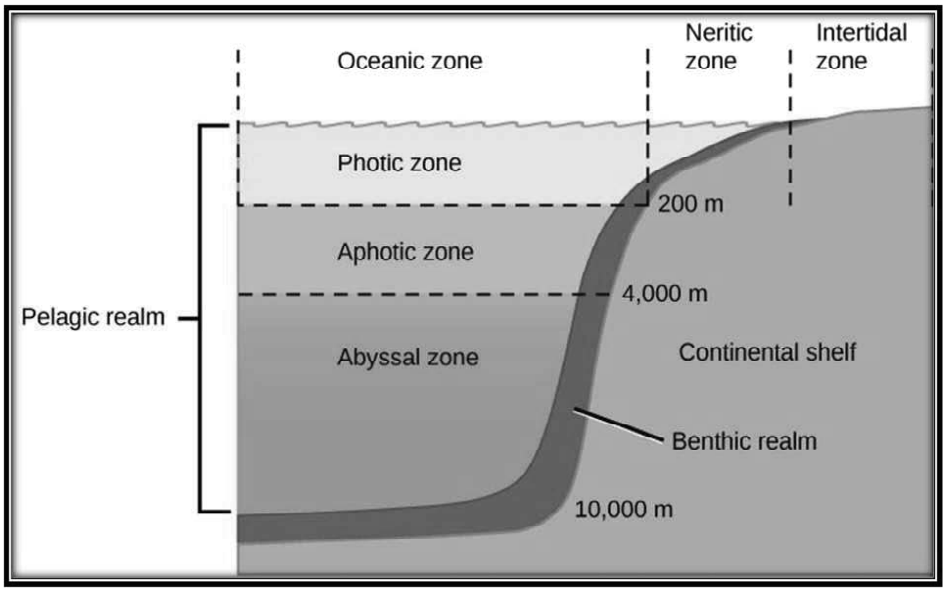

Fig. 3.28 *Zones in an Ocean*

3.7.1 Types of Zooplankton

The most noteworthy types of zooplankton are as follows:

Radiolarians, Foraminiferans, Dinoflagellates, Cnidarians, Crustaceans and Molluscs.

Radiolarians

Radiolarian (protozoan) are found in the upper layers of all oceans. Radiolarians are mostly spherically symmetrical and are well known for their complex and beautifully sculptured, though minute, silica skeletons, commonly referred to as tests. These tests are highly perforated in a variety of patterns forming a series either of lattice like plates or of loose needle-shaped spicules. Pseudopodia extend out via the perforated skeleton. A chitinous central capsule encloses the nuclei and divides the cytoplasm into two zones. The outer cytoplasm contains many vacuoles that control the organism's buoyancy.

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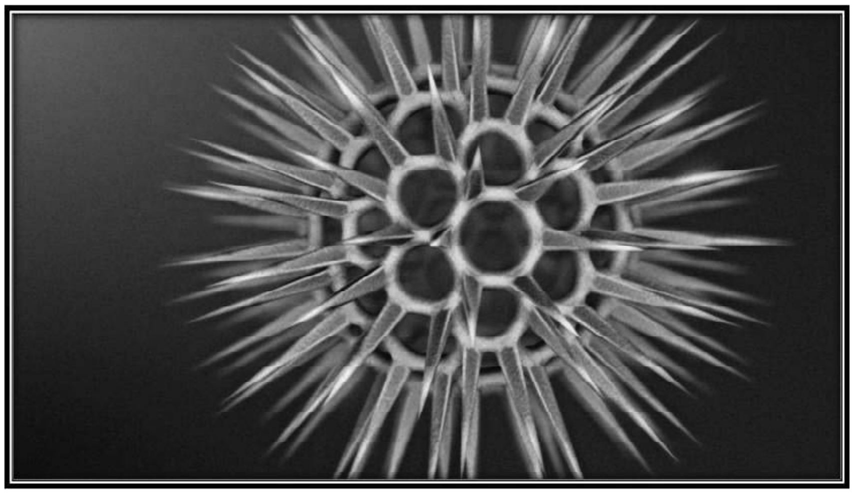

Fig. 3.29 Radiolarian

Foraminiferans

Foraminifera are unicellular protista characterized by streaming granular ectoplasm for catching food as well as for other habits; and generally an external shell (known as test) of diverse forms and materials. Tests of chitin are supposed to be the most primitive type. Most foraminiferans are marine and the majority of them reside on or within the seafloor sediment, although a few floats in the water column at various depths. A few of them are reported from freshwater or brackish conditions, as well as some very few soil species have been recognized via molecular analysis of small subunit ribosomal DNA.

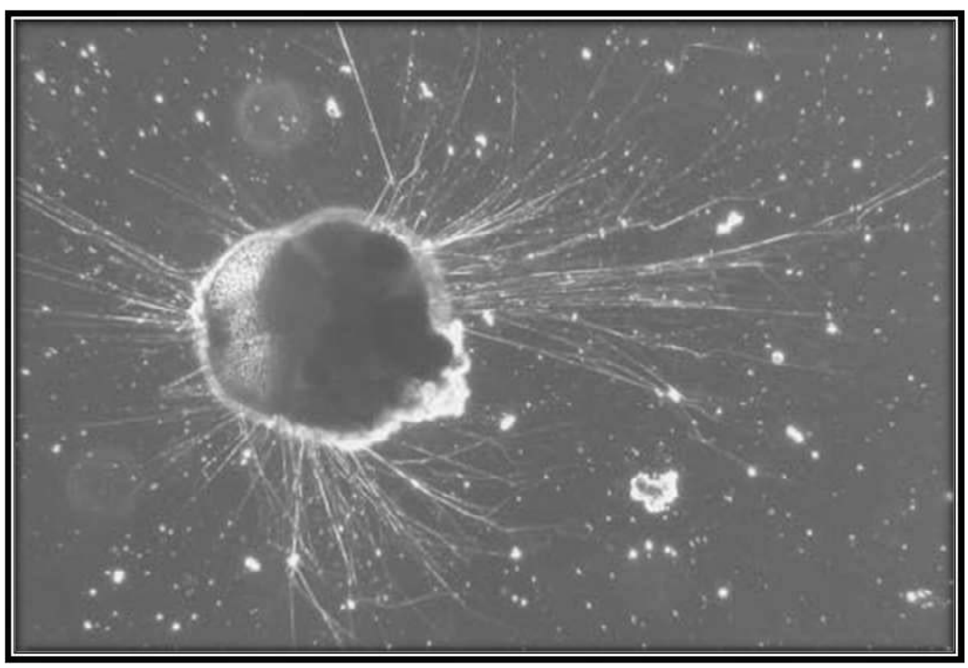

Fig. 3.30 Foraminiferan

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Dinoflagellates

Many dinoflagellates are known to be photosynthetic, but a large fraction of these are in fact mixotrophic, combining photosynthesis with ingestion of prey. Several of them are luminescent and produce light. The perforation in the thecal plates are the characteristic features of dinoflagellates and help in the identification. Figure 3.31 is depicting a Dinoflagellate.

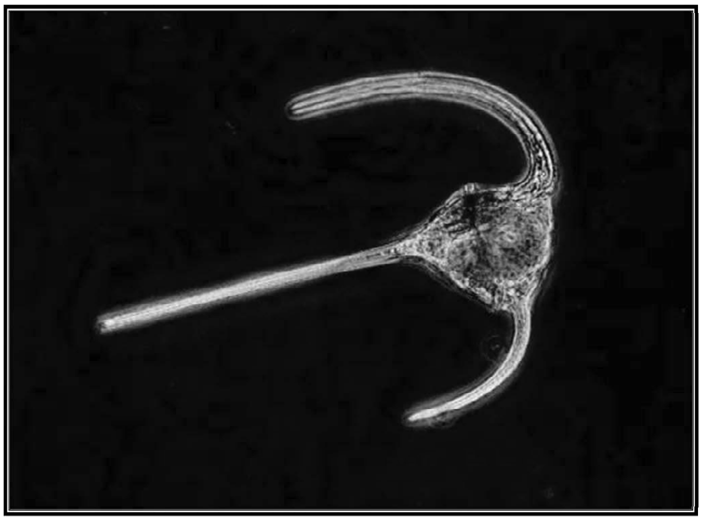

Fig. 3.31 *Dinoflagellate*

Cnidarians

Cnidarians are invertebrates that are characterized by specialized cells called 'cnidocytes', which are used to capture their prey. They belong to the phylum Cnidaria. All cnidarians are aquatic. Most of them are marine. Cnidarians are a little more complex than sponges. They have radial symmetry and tissues. There are more than 10,000 cnidarian species known to exist, such as jellyfish and corals. Figure 3.32 is depicting a cnidarian.

Fig. 3.32 *Cnidarian*

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Crustaceans

Crustaceans are one of the most important marine animals. They are known by common names like crabs, lobsters, barnacles, and shrimp. They are more diverse than any other group of arthropods. Crustaceans are second or third in abundance of all categories of animal life after insects and vertebrates. Humans rely heavily on crustaceans for food and crustaceans are also an important prey source for marine life in the ocean food chain for a diverse range of animals like whales, fish, as well as pinnipeds. They live in inland and ocean waters from the Arctic to the Antarctic as well as from elevations in the Himalayas up to 16,000 feet to well below sea level. Figure3.33 is depicting different types of crustaceans.

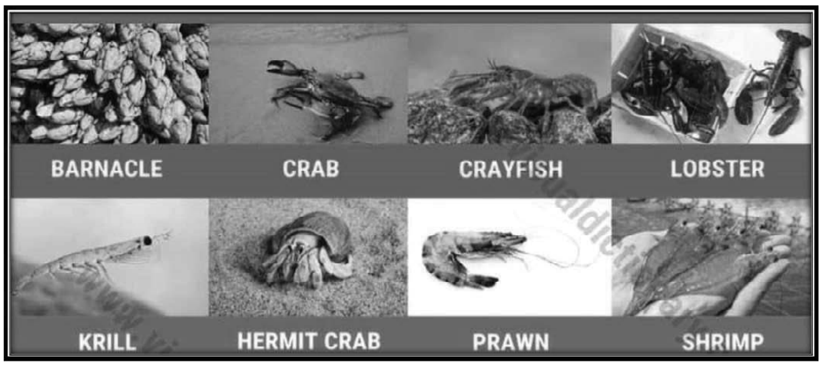

Fig. 3.33 *Different Types of Crustaceans*

Molluscs

Molluscs are a highly diverse group of organisms, which include squid species sea slugs and sea snails. Molluscs include a huge component of all marine life. The embryonic or larval shell of molluscs are included in zooplankton.

Fig. 3.34 *Molluscs*

NOTES

Check Your Progress

14. Define phytoplankton.
15. Write the Classification of phytoplankton on the basis of colour.
16. Which class of phytoplankton have variety of light-absorbing pigments, known as phycobilins?
17. Define zooplanktons.
18. What are the types of zooplankton.

3.8 ANSWERS TO 'CHECK YOUR PROGRESS'

1. Biological limnology aims at understanding the flora and fauna; existing in the freshwater bodies like lakes, ponds, streams, rivers, etc.
2. Fresh water (or freshwater) is any naturally occurring source of water; containing low concentrations of dissolved salts and other total dissolved solids.
3. Periphytons or Aufwuchs are the plants and animals that attach or cling to the stems and leaves of rooted plants or other surfaces projecting above the bottom.
4. Those aquatic system which contains standing or stagnant water are referred to as Lentic aquatic systems. Lentic water systems are closed system which are generally formed in small or large depressions on earth's surface; lacking any exit for the water to flow out.
5. A biotic community, also known as a '*biota*' or '*biocoenosis*', is the group of organisms that live together and interact with each other within an environment or habitat. Together, the biotic community and the physical landscape or abiotic factors make up an ecosystem.
6. Lentic systems derive most of their waters from rains, surface run-offs or from underground sources.
7. Phytoplankton and periphytons are the chief primary producers in the lentic water system.
8. Anadromous and catadromous fish are two types of fish which live in a separate habitat than the habitat they have spawn. Salmon, smelt, striped bass, shad, and sturgeon are examples of anadromous fish while eels are an example of catadromous fish.
9. Lotic aquatic systems are those systems which contain flowing waters. For instance; springs, streams, and rivers are familiar examples of lotic systems. The primary function of these lotic bodies of water is to carry the surplus rain water back to the sea.
10. Fishes are perhaps the best-known inhabitants of lotic water system.Fishes exhibit several adaptations to survive in the water flow like dorso-ventrally flattened body, streamline body structure, eyes on top, lateral line system, etc.
11. A stream can be defined as a body of water with a current and is smaller than a river. When merged, they can form a bigger body of water either flowing or nonflowing water ecosystem (like lakes, river, etc.).

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12. Holoplankton refers to the organisms that remain in planktonic form for their entire lifetime, For instance; algae, jellyfish, etc. while meroplankton refers to the organisms, who live as planktonic organism only at some stages of their lifecycle, for instance; larvae of starfish, worms, sea urchins, fish, etc.
13. Temperature directly or indirectly affects the vertical distribution of plankton as follows:
    (i) Selection of some optimal temperature by some moving plankton.
    (ii) Failure of certain immobile plankton to settle down at certain temperature levels.
14. Phytoplankton are small microscopic, unicellular and photosynthetic organisms which freely float in water bodies. Phytoplankton composed of both eukaryotic as well as prokaryotic species which colonizes upper euphotic part of the water column ranging from freshwater to ocean conditions.
15. Classification of Phytoplankton on the basis of colour (Proposed by W.H. Harvey in 1836):
    (a) Chlorospermae: They are green algae and fresh water forms.
    (b) Melanospermae: They are brown algae.
    (c) Rhodospermae: They are red algae.
16. The cryptophyceaens are phytoplanktons, most of which have plastids. And have variety of light-absorbing pigments, known as phycobilins, that are able to absorb wavelengths which are not accessible to other plants or algae, allowing them to live in a variety of different ecological niches.
17. Zooplanktons are microscopic, unicellular or multicellular forms with size ranging from a few microns to a millimetre or even more. Apart from size variations, zooplankters exhibit differences in morphological features as well as taxonomic positions consisting of representatives from almost every taxon of the animal kingdom.
18. The most noteworthy types of zooplankton are: radiolarians, foraminiferans, dinoflagellates, cnidarians, crustaceans and molluscs.

3.9 SUMMARY

- Fresh water (or freshwater) is any naturally occurring water containing low concentrations of dissolved salts and other total dissolved solids.
- Freshwater biota may be classified on the basis of their position in the energy or food chain.
- Autotrophs includes the green plants and the chemosynthetic microorganisms.
- Phagotrophs includes primary, secondary and tertiary consumers, including herbivores, predators, parasites, etc.
- Saprotrophs can be further sub-classified according to nature of the organic substrate decomposed.
- The five-kingdom classification was proposed by R.H. Whittaker in 1969.

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- The five kingdoms were Kingdom Monera, Kingdom Protista, Kingdom Fungi, Kingdom Plantae and Kingdom Animalia.
- The Kingdom Monera includes prokaryotic organism like bacteria which lacks a well-organized nucleus as well as membrane bound organelles;
- Kingdom Protista includes all unicellular and colonial eukaryotes like algae, diatoms and protozoans which are unicellular eukaryotic organisms having a well-organized nucleus, membrane bound organelles and exhibit both autotrophic and heterotrophic mode of nutrition;
- Kingdom Fungi includes mushrooms, Rhizopus, etc., which are multicellular eukaryotic saprophytic organism;
- Kingdom Plantae includes autotrophic, multicellular eukaryotic organisms whose cell walls are made up of cellulose
- Kingdom Animalia include multicellular eukaryotic organisms lacking a cell wall.
- Phytoplankton are small microscopic, unicellular and photosynthetic organisms which freely float in water bodies.
- Phytoplankton are composed of both eukaryotic as well as prokaryotic species which colonizes upper euphotic part of the water column ranging from freshwater to ocean conditions.
- The range of the Phytoplankton cells can vary in size from about 1 ìm to 1 mm.
- Phytoplankton cells contains chlorophyll which helps them to synthesize food in the presence of sunlight.
- Phytoplankton act as primary link in energy pathway to higher trophic level via several food chains.
- Eutrophication refers to the process in which a water body becomes overly enriched with nutrients, leading to excessive growth of growth of algae and planktons.
- Eutrophic waters can eventually become 'dead zones' that are no longer capable of supporting aquatic life (both plants and animals).
- The name zooplankton is derived from the Greek words *zoon*; animal; and planktos; wandering.
- Zooplanktons are microscopic, unicellular or multicellular forms with size ranging from a few microns to a millimeter or even more.
- Those aquatic system which contains standing or stagnant water are referred to as Lentic aquatic systems.
- Stratification causes different layers of a lentic water to have different oxygen content and nutrient status.
- Abiotic community, also known as a biota or 'biocoenosis', is the group of organisms that live together and interact with each other within an environment or habitat.
- Together, the biotic community and the physical landscape or abiotic factors make up an ecosystem.
- Streams are zones where a quick flow of shallow water creates a shearing stress on the stream bed, leading to a rocky or gravel substratum covered by a fully oxygenated water.

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- A stream can be defined as a body of water with a current, and is smaller than a river.
- Diatoms are among the most significant and productive microscopic sea organisms and serve directly or indirectly as food for many animals.
- Those organisms that attach firmly to a substrate (submerged rocks, plants, debris) but do not penetrate it (in contrast to plants rooted in the bottom or certain parasites) are collectively called known as 'Aufwuchs'.
- Algae are chief part of a wetland ecosystem. Algae supply food for animals like small fish, insects and invertebrates.
- There are four main types of hydrophytes (plants that only live in or on water) in a wetland System.
- Submerged, floating, emergent shrubs and various amphibious trees.
- Submerged water plants are not rooted in the substrate and floating beneath the surface, i.e., they are completely submerged in water.
- Emergent water plants are rooted in the substrate, however their leaves and flowers extends into the air. They are present near the shoreline.
- Floating-leaved water plants: Floating-leaved water plants are rooted in the substrate but with floating leaves. Their roots can easily suck nutrients.
- Those aquatic system which contains standing or stagnant water are referred to as Lentic aquatic systems.
- Lotic aquatic systems are those systems which contain flowing waters. For instance; springs, streams and rivers are familiar examples of lotic systems.
- The primary function of these lotic bodies of water is to carry the surplus rain water back to the sea.
- Lotic water system exhibits longitudinal zonation or profile instead of horizontal as seen in lakes and ponds discussed in the previous sections. In 1963, Lilies and Botosaneanu have recognized two major subdivisions of a stream/river course.
- The term plankton was first proposed by an Oceanographer, Victor Hensen in 1887. The term 'Plankton' collectively refers to all the organisms present in marine as well as freshwater system.
- Planktons are non-motile organisms that cannot swim against the water current.
- Phytoplankton are autotrophs or producers, e.g., algae, cyanobacteria, dinoflagellates, diatoms, etc.
- 1Zooplankton includes primary consumers, i.e., those planktonic organism who feed on other plankton, e.g. larvae of fish, small protozoans, as well as other animals.

3.10 KEY TERMS

- **Freshwater Ecosystem:** Freshwater ecosystems are a part of earth's aquatic ecosystems. They include lakes, ponds, rivers, streams, springs, bogs, and wetlands, etc.

- **Limnology:** Branch of science that deals with fresh water ecosystem.
- **Flora:** Flora refers to all plant species present in an ecosystem.
- **Fauna:** Fauna refers to all animal species present in an ecosystem.
- **Lentic communities:** Lentic communities are aquatic communities that occur in still waters where the current does not have one flow of direction such as; ponds, lakes, and wetlands.
- **Lotic communities:** Lotic communities are found in running water bodies such as streams and rivers. Lotic or flowing ecosystems are river channels and other related aquatic environments creek, brook, spring, or stream.
- **Phytoplankton:** Phytoplankton are the autotrophic (self-feeding) components of the plankton community and a key part of ocean and freshwater ecosystems.
- **Zooplanktons:** Zooplankton are heterotrophic (sometimes detritivorous) plankton drifting in oceans, seas, and bodies of fresh water.
- **Autotrophs:** Autotrophs are organisms that can produce their own food, using materials from inorganic sources.
- **Heterotrophs:** A heterotroph is an organism that cannot manufacture its own food by carbon fixation and therefore derives its intake of nutrition from other sources of organic carbon, mainly plant or animal matter.
- **Phagotrophs:** Any heterotrophic organism that feeds by ingesting organisms or organic particles, which are digested within its body.
- **Saprotrophs:** An organism that feeds on or derives nourishment from decaying organic matter.
- **Mixotrophs:** Mixotrophs act as both producers & consumers according to environmental conditions. In the presence of abundant light and nutrients they perform the process of photosynthesis while in the absence of these resources they feast on other planktonic organisms to fulfil their nutritional requirements.
- **Aufwuchs:** Those organisms that attach firmly to a substrate but do not penetrate it are collectively called known as "Aufwuchs".
- **Holoplankton:** Holoplankton refers to the organisms that remain in planktonic form for their entire lifetime, For instance; algae, jellyfish, etc.
- **Meroplankton:** Meroplankton refers to the organisms, who live as planktonic organism only at some stages of their lifecycle, for instance; larvae of starfish, worms, sea urchins, fish, etc.

3.11 SELF ASSESSMENT QUESTIONS AND EXERCISES

Short- Answer Questions

1. Write the classification of freshwater biota.
2. Why the profound zone is also known as aphotic zone?

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3. Which type of heterotrophs are present in benthic zone?
4. How the zooplankton play an important role in the marine food web?
5. Write the difference between rithron and potamon zone.
6. Why Presence of water current is considered as the leading feature of a lotic system?
7. Write few adaptations present in insects to thrive well in the lotic system.
8. What are mixotrophs? What is their unique feature?
9. Write few general features of planktons.
10. Write the classification of planktons based on local environmental distribution.
11. Why most of the organism fond profundal zone, are anaerobic in nature?
12. Write the classification of zooplanktons on the basis of organization of the body structure.

Long- Answer Questions

1. Briefly describe the various zones of a lentic aquatic body.
2. Explain the major characteristics of lentic aquatic system.
3. Briefly analyze the biotic communities present in lakes.
4. Describe the major producers of the pond ecosystem.
5. Explain the common adaptation seen in biotic communities residing in rhithron zone giving suitable examples.
6. Give few factors which are responsible for horizontal distribution of the plankton in the water.
7. Discuss the biota associated with lotic water system in detail.
8. Analyze the diversification in the food requirement of plankton.
9. Describe the ecological significance and importance of plankton in detail.
10. Describe the classification of phytoplankton based on pigment and morphological characters.

3.12 FURTHER READING

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UNIT 4 WATER MANAGEMENT

NOTES

Structure

4.0 INTRODUCTION

Water is an essential resource for all life on the planet. Of the water resources on Earth, only 2.5 percent of it is fresh. Two-thirds of the freshwater is locked up in ice caps and glaciers. Of the remaining one percent, a fifth is in remote, inaccessible areas and much seasonal rainfall in monsoonal deluges and floods cannot easily be used. As time advances, water is becoming scarcer; having access to clean, safe, drinking water is limited among countries. At present, only about 0.08 percent of all the world's fresh water is exploited by mankind in ever increasing demand for sanitation, drinking, manufacturing, leisure and agriculture. Due to the small percentage of water remaining, optimizing the fresh water we have left from natural resources has been a continuous difficulty in several locations worldwide.

Water is essential for our survival. The field of water resources management will have to continue to adapt to the current and future issues facing the allocation of water. With the growing uncertainties of global climate change and the long-

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term impacts of management actions, the decision-making will be even more difficult. It is likely that ongoing climate change will lead to situations that have not been encountered. As a result, alternative management strategies are sought for in order to avoid setbacks in the allocation of water resources.

Ideally, water resource management planning has regard to all the competing demands for water and seeks to allocate water on an equitable basis to satisfy all uses and demands. As with other resource management, this is rarely possible in practice.

One of the biggest concerns for our water-based resources in the future is the sustainability of the current and future water resource allocation. As water becomes scarce, the importance of water management grows vastly—finding a balance between humans' needs and the essential step of water resources sustainability in the environment. There are many regions where our freshwater resources are inadequate to meet domestic, economic development and environmental needs. In such regions, the lack of adequate clean water to meet human drinking water and sanitation needs is indeed a constraint on human health and productivity and hence on economic development as well as on the maintenance of a clean environment and healthy ecosystems.

The term 'wetland' encompasses many different types of ecosystems found throughout the country, including freshwater or saltwater swamps, mossy bogs, fertile floodplains, seaside lagoons, and grassy fens. Urban development and agriculture are some of the largest quantifiable causes of wetland destruction over time because they facilitate the degradation of habitats through nutrient loading and sedimentation. The construction of impervious surfaces like roads, sidewalks, and parking lots can direct nutrient-rich runoff to these delicate areas in levels that exceed nature's ability to naturally manage. Managing wetland ecosystems gives a substantial contribution to biodiversity conservation and restoration. It needs decision-makers who are involved in different management strategies to cause restoration and improvement of an ecosystem due to globally ecological and regional economic values of wetlands.

Waterborne diseases are conditions (meaning adverse effects on human health, such as death, disability, illness or disorders) caused by pathogenic micro-organisms that are transmitted in water. These diseases can be spread while bathing, washing, drinking water, or by eating food exposed to contaminated water. While diarrhoea and vomiting are the most commonly reported symptoms of waterborne illness, other symptoms can include skin, ear, respiratory, or eye problems. Waterborne diseases are impacted by a country's economy and also impact the economy by being costly to deal with.

In this unit you will study about properties of water, physical characteristics of water, chemical characteristics of water, biological characteristics of water, waste water treatment, inland water conservation, causes of pollution of aquatic resources and their management, wetlands their problems and management and water borne human diseases.

4.1 OBJECTIVES

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After going through this unit you will be able to:

- Understand the properties of water,
- Comprehended the physical, chemical and biological characteristics of water,
- Analyse waste water Treatment,
- Discuss inland water Conservation
- Describe the causes of pollution of aquatic resources and their management,
- Explain the wetlands their problems and management,
- Analyse various water borne human diseases, their symptoms and steps to prevent them.

4.2 WATER MANAGEMENT

Life without water is impossible on earth owing to its several uses in day-to-day life. Water can be used for several direct and indirect purposes. Direct purposes include activities like drinking, bathing, and cooking, on the other hand indirect purposes are the utilization of water in industrial, medical, commercial and agricultural processes. Thus, in a nutshell, some of the major uses of water can be summarized as:

- Life on planet earth is possible due to the presence of water.
- Every living organism on planet earth-be it plants or animals needs water for its physiological and metabolic needs.
- Aquatic system especially fresh-water system serves as the prime habitat for several plant and animal species.
- Aquatic system provides essential life support system for living organisms.
- Water is one of the major abiotic elements present on earth.
- Water fulfils household needs like drinking, bathing, etc.
- Water sports acts as great recreational activities.
- It is widely used in industrial and commercial purpose like in paper industry.
- Hydroelectric power plants generates electricity.
- Agricultural activities like irrigation, animal feeding operations.
- Medical activities like in haemodialysis, dental procedures, etc.

Thus, in conclusion, water is required to carry out all the day to day life activities as well as for industrial, agricultural, medical and commercial activities.

Hydrological Cycle

Hydrological cycle is also referred to as water cycle. It refers to as the continuous process by which water is circulated throughout the earth and its atmosphere. During the hydrological cycle, the earth's water enters the atmosphere via evaporation from bodies of water and from ground surfaces. Plants and animals

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also add water vapour to the air by transpiration. As it rises into the atmosphere, the water vapour condenses to form clouds. Rain and other forms of precipitation return it to the earth, where it flows into bodies of water and into the ground, beginning the cycle again. Figure 4.1depicts the hydrological cycle or water cycle.

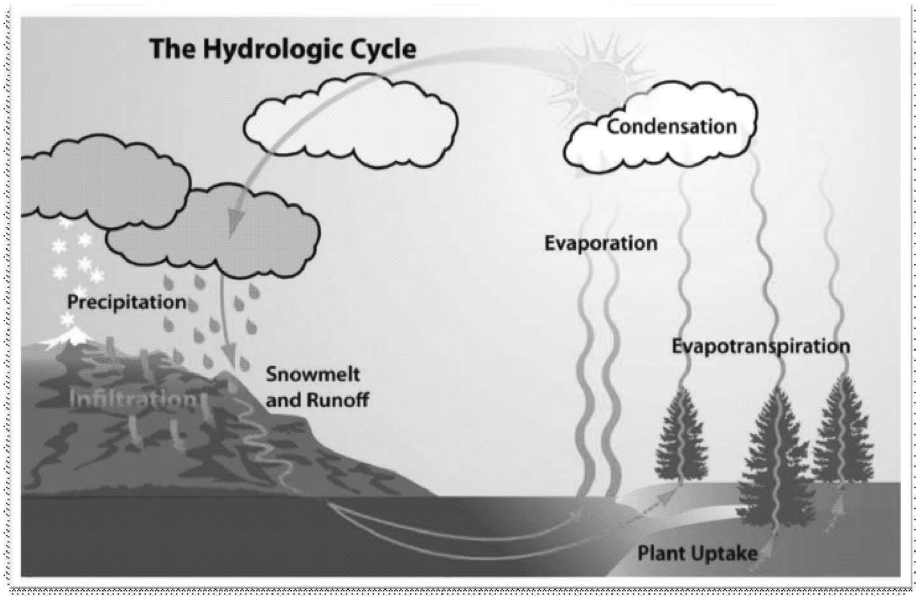

Fig. 4.1 *Water Cycle*

Distribution of Water on Earth's Surface

As depicted in the figure, 97% of the earth's water is in the oceans or sea as is referred to as saline water. Only 3% of the water present on the continents is freshwater. Sea water or saline water cannot be used for drinking or household purposes. Thus, we depend heavily on freshwater sources for carrying out our day to day life activities.

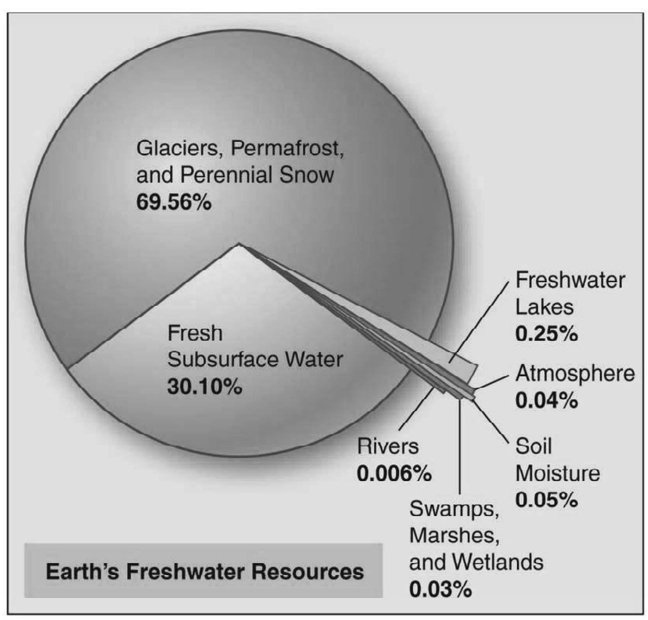

Fig. 4.2 *Distribution of Freshwater on Earth's Surface*

Figure 4.2 depicts the distribution of freshwater on earth's surface.

Properties of water

Water has three characteristics, i.e., physical, chemical, and biological characteristics. The quality of the raw water can be checked and analysed by studying and testing these three characteristics. In the next section, we will be discussing these characteristic properties of water.

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4.2.1 Physical Characteristics of Water

Water has several unique physical properties as discussed below

1. Colour of Pure Water

Water is a colourless liquid. The colour of the water is due to the presence of suspended particles as well as organic matter in it. For instance, greenish colour of pond water is due to the presence of organic substance or algae in it. The standard unit of colour is that which is produced by one milligram of platinum cobalt dissolved in one litre of distilled water. Tintometer is a kind of visual colour measuring instrument. It measures colour scale unit which is an international acknowledged specific colour method as a standard to measure the colour of liquid, solid, gelatin, and powder samples.

2. Taste and Odour of Pure Water

Water is a tasteless and odourless liquid. The taste or odour of a particular water sample is due to the presence of inorganic or organic substance present in it. For instance; presence of inorganic material gives earthy smell to water whereas dead and decaying organic matter gives a foul smell to water.

3. Temperature of Water

Temperature of surface water varies from space and time due to changing atmospheric conditions whereas that of ground water fluctuates with depth. Temperature of water ranges anywhere from 0 to 100 degree Celsius. It is measured using thermometers.

4. Electrical Conductivity

Electrical conductivity refers to the ability of a substance to conduct an electric current. The presence of charged particles like cations (positively charged particles) and anions (negatively charged particles) makes water conductive in nature. The total amount of dissolved salts present in water can be easily estimated by measuring the specific conductivity of water. Pure water is less conductive compared to other. Conductivity can be easily measured by using EC meters. Electrical conductivity of water is directly related to its temperature. Unit of measurement for electrical conductivity is millimho per centimetre (mmhos/cm) at standard temperatures and it ranges from 100-1,00,000.

5. Universal Solvent

Water is called the 'Universal Solvent', as it is capable of dissolving more substances than any other liquid. Water molecules have a polar arrangement of oxygen and hydrogen atoms one side (hydrogen) has a positive electrical charge and the other side (oxygen) had a negative charge. This property allows the water molecule to become attracted to many other different types of molecules.

6. Turbidity of Water

Turbidity refers to the measure of relative clarity of a liquid. It is an optical characteristic of water and is a measurement of the amount of light that is scattered by material present in the water when a light is passed through the water sample. Turbidity is directly proportional to light scattered, i.e., higher the intensity of scattered light, higher is the turbidity of water. The material that increases the turbidity of water includes slit, tiny organic matter, inorganic material, clay, plankton, dissolved matter as well as other microscopic organism. Higher turbidity makes the water cloudy or opaque. In fact, turbidity of the water is an indicator of potential pollution present in the water bodies. Excessive turbidity, cloudiness or opaqueness in drinking water is not only unappealing, but also unhealthy. High turbidity can provide habitat for pathogens which may lead to outbreak of water borne diseases. The turbidity of the water is measured by using an instrument known as turbidity rod or by a turbidity meter with optical observations. Turbidity rod consists of a graduated aluminium rod to give turbidity directly in silica units (mg/l). Turbidity meter works on the principle of measuring the interference caused by the water sample to the passage of light rays. Turbidity of water is expressed as the amount of suspended matter in mg/l or parts per million (ppm). The standard unit is that which is produced by one milligram of finely divided silica (fuller's earth) in one litre of distilled water.

7. Cohesion

Cohesion refers to the attractive force present between similar molecules in the same phase. Water's hydrogen bonds are mostly accountable for its cohesive properties. Cohesion helps hold a column of water together against the force of gravity. For instance; cohesion helps in the transportation of water from a tree's roots to its leaves.

8. Adhesion

Adhesion refers to the attractive force present between molecules in two different phases like between liquid and solid. For instance; adhesion between water molecules and the molecules in tube-like structures in the tree trunk plays an important role in transportation of water from a tree's roots to its leaves.

9. Surface Tension

Surface tension refers to the property of the surface of a liquid that allows it to resist an external force, due to the cohesive nature of its molecules. Besides mercury, water has the highest surface tension for all liquids which is due to the hydrogen bonding in water molecules. The surface tension of water causes water molecules at the surface of the liquid (in contact with air) to hold closely together, forming an invisible film. The surface tension of water is 72 dynes/cm at 25°C.

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10. Specific Heat

Specific heat refers to the amount of heat required to raise the temperature of a 1gram sample of a substance by one degree Celsius. The specific heat of water is 4.184 joules per gram per degree Celsius. Water has a very high specific heat as its polar structure allows it to form a network of hydrogen bonds. When heat energy is added, most of it is used to disrupt the hydrogen bonds, rather than to heat the molecules. Water's high specific heat has some significant biological consequences. Due to its high specific heat, water can absorb or lose a substantial amount of heat before its exhibits change in temperature. This helps us to withstand a wide range of environmental temperatures as water makes up nearly 60% to 70 % total weight of a human body.

11. High Latent Heat of Fusion

Latent heat of fusion is the heat required by a specific quantity of the substance to change its state from a solid to a liquid, at constant pressure. 80 calories are required to change one gram of ice into water without changing its temperature.

12. Highest Latent Heat of Evaporation

The heat of vaporization is referred to as the amount of heat needed to turn 1 g of a liquid into a vapour, without a rise in the temperature of the liquid. The heat of vaporization of water is the highest known. Major share of the solar energy dissipates in the evaporation of water from the world's aquatic ecosystems. This helps in maintaining the hydrological cycle on earth.

13. Highest Density at 4^0 C

This specific feature helps in expanding water from both above and below the surface and making it lighter. This property prevents the water bodies like lake from freezing.

4.2.2 Chemical Characteristics of Water

The following are the chemical characteristics of water

1. Total Dissolved Solids (TDS)

Total dissolved solids present in water can be determined by evaporating a sample of water and then weighing the dry residue left on the filter paper. TDS is measured in ppm or mg/l. The amount of TDS in water determines its suitability for our consumption. Table below depicts how the quality of water changes with the TDS values.

S.NO	TDS Values in ppm	Type of water
1	<1000	Fresh Water
2	1000-10,000	Brackish Water
3	10,000-1,00,000	Saline Water
4	>1,00,000	Hypersaline or Brine

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2. The pH of Drinking Water

The pH value of pure water is 7 i.e. pure water is neutral. The pH value is defined as the effective concentration of H^+ ions present in water. Water is considered to be acidic if pH value is less than 7, however, it is said to be alkaline if pH value is greater than 7. The range of pH value varies from 0 to 14. Permissible pH value for public supplies may range between 6.6 and 8.4.

The alkalinity is caused by the presence of bicarbonate of calcium and magnesium or by the carbonates of hydroxides of sodium, potassium, calcium, and magnesium. Some, but not all of the compounds that cause alkalinity also cause hardness. The pH value is measured by using pH meters.

3. Hardness of Water

Hard waters are generally undesirable as they may lead to consequences like more soap consumption, making food tasteless, causing corrosion, skin hardening, scaling of boilers, incrustation of pipes, etc. Hardness of water can be divided into two categories:

- **Temporary Hardness**: If the hardness of water can be simply removed by boiling it or by adding lime water to it then it is known as temporary hard water. The bicarbonates and carbonates of calcium and magnesium are usually responsible for causing temporary hardness in water. Temporary hardness is also known as carbonate hardness. Carbonate hardness is equal to the total hardness or alkalinity whichever is less
- **Permanent Hardness:** If the hardness of water cannot be removed by simply boiling it then such water is known as permanent hard water. The sulphates, chlorides, and nitrates of calcium or magnesium are responsible for causing permanent hardness in water. Permanent hardness is also known as non-carbonate hardness. Non-carbonate hardness is the total hardness in excess of the alkalinity. If the alkalinity is equal to or greater than the total hardness, there is no non-carbonate hardness.

4. Chloride Content

The total chloride content of water can be easily measured by titrating the sample of water to be tested with standard silver nitrate solution using potassium chromate as indicator.

5. Nitrogen Content

Nitrogen can be present in water in different forms like free ammonia, organic matter, nitrites or nitrates. Presence of nitrites in water proves to be highly dangerous. On the other hand, large amount of nitrates in the water can cause disease like blue baby disease or methemoglobinemia.

6. Salinity of Water

Salinity of water occurs due to the presence of sodium and chloride ions in water.

NOTES

7. Major Cations Present in Water

Calcium, Magnesium, Sodium, and Potassium are the major cations present in water

8. Major Anions Present in Water

Bicarbonates, Carbonate, Chloride, Sulphate, Nitrate, and Phosphate are the major anions present in water.

9. Trace Elements Present in Water

Mostly Aluminium, Arsenic, Barium, Bromide, Cadmium, Chromium, Cobalt, Copper, Lead, Zinc, Nickel, Phosphate, Silver, Tin and Vanadium. Some of the trace elements are essential for growth of living beings whereas others are dangerous or toxic to health and has the potential to cause severe health implications.

4.2.3 Biological Characteristics of Water

1) Oxygen Present in The Water

Dissolved oxygen is the amount of oxygen that is present in water. Water bodies receive oxygen from the atmosphere and from aquatic plants. Running water, such as that of a swift moving stream, dissolves more oxygen than the still water of a pond or lake. As mentioned above, oxygen gas is absorbed by the water from the atmosphere but it is being consumed by organic matter present in it. Therefore, if the oxygen gas present in water is than its normal saturation level, it indicates the presence of organic matter which makes the water unsuitable for consumption.

2) Presence of Organic Matter in the Water

The amount of organic matter present in the water can be assessed by supplying oxygen to the water sample under observation. The organic matter present in water will start consuming the oxygen and undergoes oxidation. Thus, Biological Oxygen Demand (BOD) or Biochemical Oxygen Demand (BOD) is referred as the amount of oxygen needed or demanded by aerobic microorganisms to break down the organic matter present in a certain sample of water at a specific temperature over a given period of time. BOD of water sample is evaluated by measuring the oxygen consumed by the bacteria from the decomposition of organic matter over a period of five days at a specific temperature of 20 degree Celsius. A lot of factors influence the BOD of water like temperature, pH of the water sample, inorganic substance present in the water, kind of aerobic microorganisms present in water, amount and type of organic matter present in the water sample, etc. BOD values indicate the polluting potential of water. A BOD value of less than 1mg/L indicates pure drinking water, BOD value between 2-8mg/L indicates moderately polluted water whereas a BOD value greater than 8mg/L indicates severely polluted water unfit for consumption. BOD finds its prime significance in sewage treatment plants. It indicates the respiration rate in sludge, soil, garbage, etc.

NOTES

3) Presence of Disease-Causing Microorganism

Water can support the growth several organisms. In some cases, it is advantageous as certain yeasts can provide good quality of bread and beer. However, some microorganisms are unhealthy and even life threatening. Some of the example are given below

a) Infective agent: *Salmonella typhi* (Bacteria) (Disease Caused- Typhoid fever)

The bacilli are excreted in the urine and faeces in the acute stage of the disease and some patients may continue to excrete S.typhi in the convalescent stage as well. A small percentage of the patients may become chronic carriers and excrete the bacilli for years. The incubation period is 2 weeks with a range of 7 to 21 days.

b) Infective agent: *Vibrio cholerae* (Bacteria) (Disease Caused- Cholera)

Serogroup O1 and 0139- are responsible for causing cholera. V.cholerae O1 occurs as two biotypes namely classical and E1 Tor. Each biotype also occurs as two serotypes namely Ogawa and Inaba. Nearly all the current cholera outbreak has been caused by the E1 Tor biotype. Man is the only host and patients remain infectious usually for a few days after recovery from clinical symptoms. Occasionally, the carrier stage may persist for several months. The chronic carriers however do not play essential role in the spread of disease. V.Cholerae can survive for long periods in the environment and can live in association with certain aquatic plants and animals, making water an important reservoir for infection. Incubation period varies from a few hours to 5 days, usually 2-3 days.

c) Infective agent: Giardia (Protozoa) (Disease Caused- Giardiasis)

This waterborne disease is transmitted via contaminated water of ponds or swimming pools or city water supply. The infection clears on its own after a few weeks. However, victims can experience intestinal problems for years to come.

d) Infective agent: Bacteria, viruses, or parasites in contaminated food and water (Disease caused- Bacillus Dysentery)

Dysentery refers to as the diarrhoea with visible blood in the stools. Shigella is the most common cause of dysentery. Shigella dysenteriae 1 is often associated with severe disease and complications. Infections with two species of *Shigella*, i.e., *S. sonnei* and *S. flexneri* result in short clinical course and negligible mortality. As only a few bacilli are enough to transmit the infection, shigella is usually transmitted via person to person.

The patients may transmit the infection in the acute stage and up to one month after illness. Infection with *Entamoeba histolytica* presents with similar clinical symptoms, however, it is rare in young children. The incubation period is usually 1-3 days. Asymptomatic carriers may transmit infection to healthy individuals. The carrier state rarely persists for long periods.

NOTES

e) Infective agent: Viral Hepatitis A, E (Disease Caused- Viral Hepatitis)

Viral hepatitis A and E are responsible for causing water borne disease. Major outbreak of viral hepatitis in India are due to hepatitis E virus. Rare outbreaks of hepatitis A, may also occur. Although, outbreaks of hepatitis A are relatively rare, as by age five most young individuals gets through natural infection. Incubation period of hepatitis E is usually one to two months. Hepatitis E infection may be preceded by other water borne disease having shorter incubation periods like acute diarrhoeal diseases (few days) and typhoid fever (one to three weeks).

f) Infective agent: *Salmonella enterica* and *Salmonella bongori* (Disease Caused- Salmonellosis)

Majority of the salmonella cases comes from ingesting water or food contaminated with faeces. Undercooked or raw food such as egg products, meat, vegetables or fruits can also carry the disease. Most vulnerable are children, pregnant women, aged individuals, and people with weakened immune systems.

g) Infective agent: Roundworms (Disease Caused- Ascariasis)

Mostly transmitted through poor hygiene. Usually found in human faeces and is transmitted from hand to mouth along with contaminated food or water.

Table 4.1 depicts the Indian standards for drinking water – Specification (BIS 10500:1991)

Table 4.1 *Indian Standards for Drinking Water*

Sl.No	Substance or Characteristic	Requirement (Desirable Limit)	Permissible Limit in the absence of Alternate source
Essential characteristics			
1.	Colour, (Hazen units, Max)	5	25
2.	Odour	Unobjectonable	Unobjectionable
3.	Taste	Agreeable	Agreeable
4.	Turbidity (NTU, Max)	5	10
5.	pH Value	6.5 to 8.5	No Relaxsation
6.	Total Hardness (as $CaCo_3$) mg/lit.,Max	300	600
7.	Iron (as Fe) mg/lit,Max	0.3	1.0
8.	Chlorides (as Cl) mg/lit,Max.	250	1000
9.	Residual,free chlorine,mg/lit,Min	0.2	--
Desirable Characteristics			
10.	Dissolved solids mg/lit,Max	500	2000
11.	Calcium (as Ca) mg/lit,Max	75	200
12.	Copper (as Cu) mg/lit,Max	0.05	1.5
13	Manganese (as Mn)mg/lit,Max	0.10	0.3
14	Sulfate (as SO_4) mg/lit,Max	200	400
15	Nitrate (as NO_3) mg/lit,Max	45	100
16	Fluoride (as F) mg/lit,Max	1.9	1.5

NOTES

17	Phenolic Compounds (as C_6H_5OH) mg/lit, Max.	0.001	0.002
18	Mercury (as Hg)mg/lit,Max	0.001	No relaxation
19	Cadmiun (as Cd)mg/lit,Max	0.01	No relaxation
20	Selenium (as Se)mg/lit,Max	0.01	No relaxation
21	Arsenic (as As) mg/lit,Max	0.05	No relaxation
22	Cyanide (as CN) mg/lit,Max	0.05	No relaxation
23	Lead (as Pb) mg/lit,Max	0.05	No relaxation
24	Zinc (as Zn) mg/lit,Max	5	15
25	Anionic detergents (as MBAS) mg/lit,Max	0.2	1.0
26	Chromium (as Cr^{6+}) mg/lit,Max	0.05	No relaxation
27	Polynuclear aromatic hydro carbons (as PAH) g/lit,Max	--	--
28	Mineral Oil mg/lit,Max	0.01	0.03
29	Pesticides mg/l, Max	Absent	0.001
30	Radioactive Materials		
	i. Alpha emitters Bq/l,Max	--	0.1
	ii. Beta emitters pci/l,Max	--	1.0
31	Alkalinity mg/lit.Max	200	600
32	Aluminium (as Al) mg/l,Max	0.03	0.2
33	Boron mg/lit,Max	1	5

Check Your Progress

1. Define Hydrological cycle.
2. What is tintometer?
3. Why water is called universal solvent?
4. Name some material that increases the turbidity of water.
5. What is the pH value of pure water? When it is considered to be acidic?
6. Name major cations and anions present in water.

4.3 WASTE WATER TREATMENT

Sewage is created by residential, institutional, commercial, as well as industrial establishments which includes household waste liquid from toilets, baths, showers, kitchens, sinks, and so forth that is disposed of via sewers. In several areas, sewage also includes liquid waste from industry. Sewage can be effectively treated at the point where it is created like in septic tanks or it can be collected and transported via a network of pipes and pump stations to a municipal treatment plant. For managing/ controlling water pollution from point sources (like sewage), treatment of waste water is essential before being discharged into aquatic bodies. Parameters which needs to be taken into consideration before discharging water are: Total solids, Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), nitrates and phosphates, oil and grease, toxic metals, etc. Waste waters should be properly treated by primary, secondary and tertiary treatments to reduce the BOD, COD levels up to the permissible levels before discharging them into aquatic bodies.

4.3.1 Step-by-Step- Waste Water Treatment Process

NOTES

Sewage treatment, or domestic wastewater treatment refers to the process of removing physical, chemical, and biological contaminants/pollutants from them. The main objective of the waste water treatment is to produce an environmentally-safe fluid waste stream (or treated effluent) or reuse the water either by humans/ animals or for any other purpose like as farm fertilizer. Conventional sewage treatment involve three stages namely primary, secondary, and tertiary treatment. Step by step process of waste water treatment is as follow:

Step One: Collection of Waste Water

- Collection of wastewater is the first step in the process of waste water treatment.
- The collection system is set in place by municipal administration as well as the private business owners.
- These collection centres ensure that all the wastewater is collected together at one place and then is directed into the central point.
- Once collected, waste water is directed into the treatment plant by using the underground drainage systems.
- Apart from the underground drainage system, exhauster tracks can also be used to direct the collected wastewater into the treatment plant.
- All the precautions like wearing protective clothing and gloves should be taken before transporting this collected wastewater into the treatment plant. Transportation should be done in hygienic conditions.
- It is also essential to ensure that the pipes or tracks do not leak.

➢ **Pre-Treatment**

- Pre-treatment involves removing large solid items like sanitary items, diapers, wipes, broken bottles, or debris etc. from the raw sewage. This is an essential step as allowing such items further in the process can damage the equipment used for treating waste water.
- Grit and sand are also removed in the process.
- After this, it is rinsed in the sewer.
- All the debris are then dried up and incinerated.
- Sand and grit are then settled out in the tanks.

➢ **Odour Control**

- Waste water also contains several dirty substances that may give it foul smell.
- Odour treatment is mainly initiated at the treatment plant.
- Odour treatment is done by containing the wastewater and treating it with chemicals.
- This chemical will automatically neutralize the odour producing elements in the wastewater.

- Odour control/treatment helps in keeping the environment and surroundings smell free.

NOTES

➢ **Screening**

- Screening involves removing all the large items/objects that may have remained even after the initial step of pre-treatment.
- Screening is done more rigorously to ensure all solid objects are removed from the waste water.
- A rigorous screening ensures clearing all the solid objects that may potentially damage the equipment later on.
- Screening also helps in removing all the unwanted solid material from waste water.
- All these solid wastes are transported and disposed-off in the landfills.

Step Two: Primary Sewage Treatment

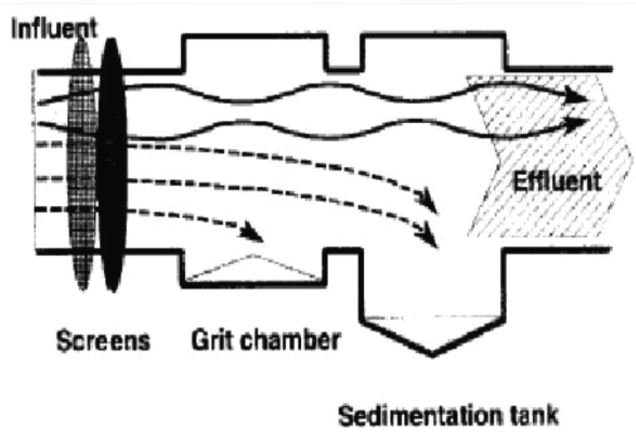

Fig. 4.3 *Process of Primary Treatment.*

Figure 4.3 is depicting the process of primary treatment.

- Primary sewage treatment involves separation of solid macrobiotic matter from wastewater.
- This process is done by pouring wastewater into the big tanks (known as big/large settlement tanks) leading to the settlement of the solid matter on the tank's surface.
- At this stage, waste water gets separated into two: first is the solid organic matter settled at the bottom of the tank and second is the remaining liquid.
- The denser waste that sinks at the bottom of the settlement tank is known as sludge.
- The wastes are then pushed to the centre by large scrappers which continuously remove them from the bottom.
- At the top, there is another layer of fats which floats since it is less dense than water. This layer of fats forms a crust.
- The water between the crust and the sludge, which is now homogenous, is taken to for secondary treatment.

- This makes the treatment more proficient.

Step Three: Secondary Sewage Treatment

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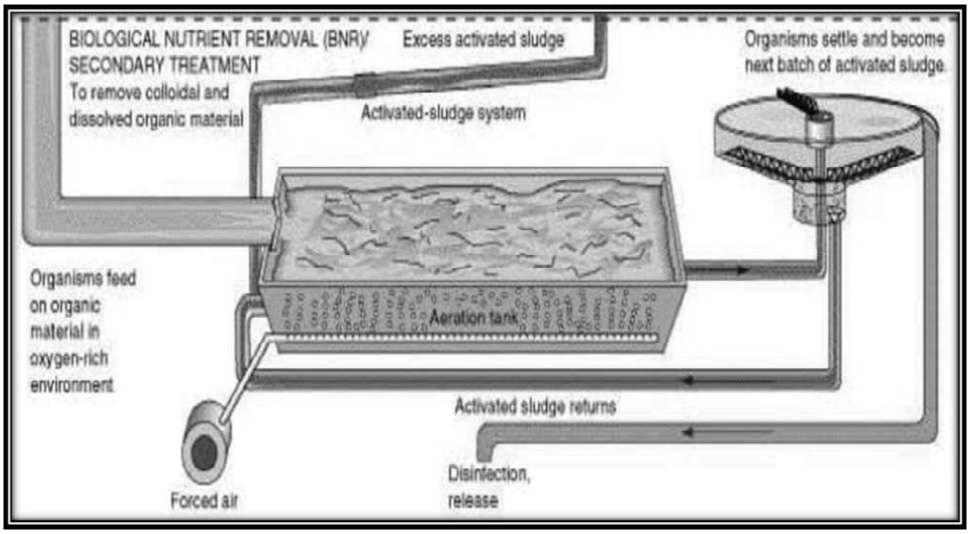

Fig 4.4 *Process of Secondary Sewage Treatment*

Figure 4.4 is depicting the process of secondary sewage treatment

- Secondary treatment is also known as activated sludge process.
- At this stage, oxygen (O_2) is introduced into the water.
- This helps break down the sludge that may have escaped the primary treatment.
- It begins with pumping air into the huge aeration tanks that has a mix of wastewater with a seed sludge.
- A small amount is pumped in to activate the growth of aerobic bacteria (which uses oxygen).
- This step also activates the growth of microorganisms which consume all the remaining organic matter.
- After sometime, debris produced will settle down at the bottom of the large tank.
- Water can pass through the huge tank in three to six hours.
- Humus and the dead bacteria settle out in another chamber for extra treatment.

Bio-Solids Handling

- The ultimate solid matter that settles down after the primary and secondary treatment procedures, are then directed into the digesters.
- Digesters are then heated strongly at the room temperature.
- Solid matter present inside the digesters undergoes anaerobic digestion.
- Production of methane gas and the formation of nutrient rich bio-solids are observed at this stage.
- Recycled methane gas is mostly used in the local firms as primary source of energy.

- It can also be used as the energy source in waste water treatment plant (for running equipment used during the process).

Step Four: Tertiary Treatment

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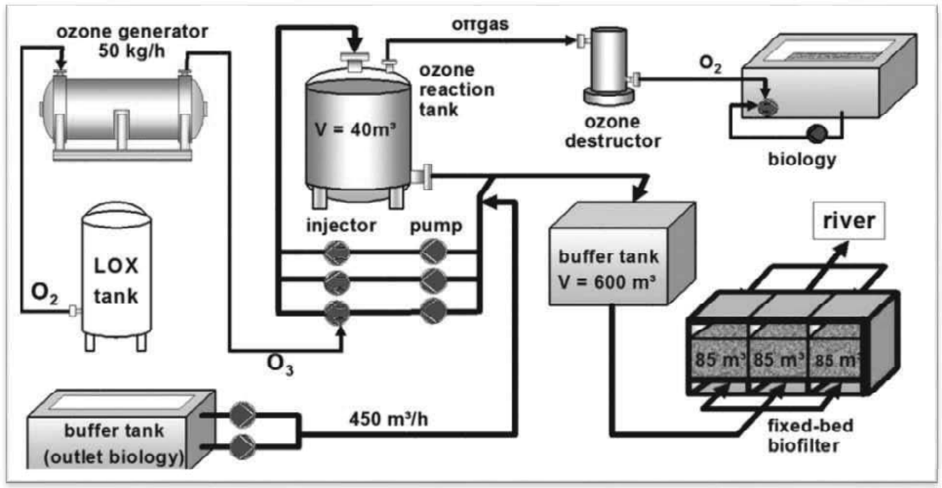

***Fig.4.5** Process of Tertiary Treatment*

Figure 4.5 is depicting the process of tertiary treatment in waste water treatment plant.

- Tertiary treatment is employed where the discharge points is very sensitive/ ecologically important.
- These sensitive points include streams or dams where the water will be used directly by plants/animals/people.

Tertiary treatment involves:

a. Chlorination of waste water.

b. Ozone treatment of waste water.

c. Use of Ultra Violet (UV) light to disinfect waste water.

d. Reducing the level of nitrogen in waste water.

  - At tertiary treatment stage, all the remaining impurities are removed from the wastewater.
  - Tertiary treatment stage is almost similar to that used in the drinking water treatment plant.
  - It helps in the removal of 99% impurities in waste water.
  - At this stage, wastewater is treated so rigorously that it produces effluent water having almost same quality as that of the drinking water.
  - Tertiary treatment of waste water is highly expensive and time-consuming process.
  - It also requires sophisticated equipment, strong chemicals, and a constant supply of energy as well as skilled labour.

Disinfection

- Disinfection is an integral process of waste water treatment plan.
- Even after going through such rigorous processes, some diseases causing organisms might be left in the water.
- In order to eradicate disease causing microorganisms, wastewater is disinfected with the mixture of sodium hypochlorite and chlorine for about 20-25 minutes.

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Step Five: Sludge Treatment

- Sludge produced and collected at the primary and secondary treatment levels of the waste water treatment plans requires a very high concentration and thickening process.
- This can be achieved by putting them into the thickening tanks to settle down and then separate it later from the water.
- The entire process of sludge treatment may take up to 24 hours.
- After sludge treatment, the remaining water will then be collected and reversed back to the large aeration tank to enable further treatment.
- The treated water is recycled for agricultural purposes.
- It can also be discharged into lakes/streams/rivers.

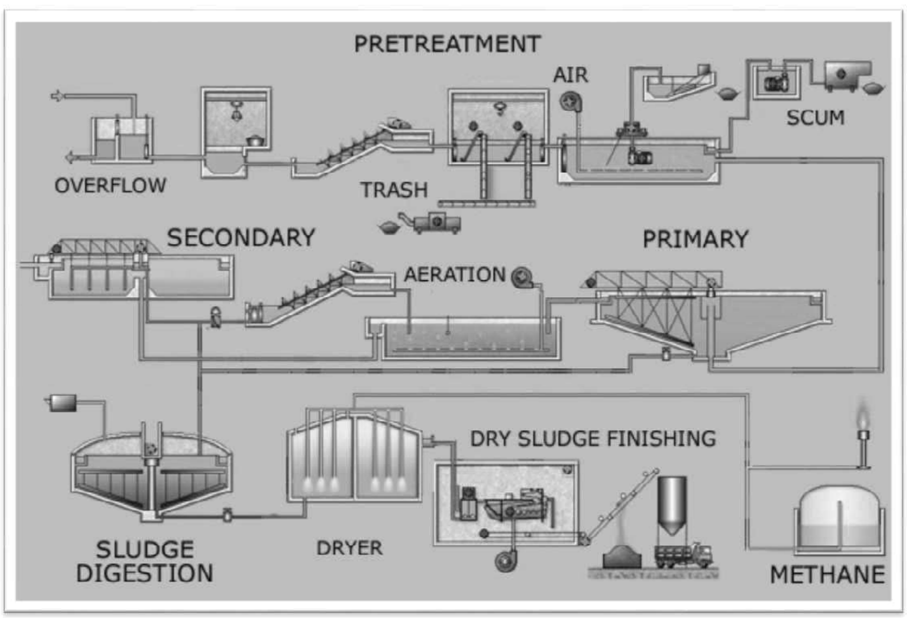

Fig 4.6 *Entire Process of Waste Water Treatment*

Figure 4.6 depicts the entire process of waste water treatment.

4.3.2 Methods of Waste Water Treatment

There are three methods of waste water treatment namely

1. Biological waste water treatment.

2. Physical waste water treatment.
3. Chemical waste water treatment.

1. Biological Waste Water Treatment:

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- Biological treatment of wastewater is done to obtain water fit for human consumption.
- Biological treatment involves the extensive use of micro bacteria that decompose the waste material or organic impurities and improve the quality of water to be used for households.

Three common methods of biological treatment are as follows:

a) **Aerobic Process:** As the name suggests, oxygen is required for this purpose. During the aerobic process, oxygen consuming bacteria decompose and devour the organic impurities of waste water and convert it to CO2 for reproduction and growth.

b) **Anaerobic Process:** This process occurs in the absence of oxygen. In the Anaerobic or fermentation process, waste or sludge present in the waste water is fermented at a specified temperature.

Composting: Composting is a kind of aerobic process, in which sludge or bio-solid is mixed with carbon sources in the presence of oxygen to remove all the impurities.

2. Physical Wastewater Treatment:

Physical wastewater treatment involves the use of physical approaches to remove impurities.

Three important physical methods strategies used to clean waste water.

a) **Sedimentation:** Sedimentation refers to the process of removing insoluble debris from the water. The first unit of sedimentation tank used during the process is known as 'Primary Sedimentation Tank' or 'Primary Settling Tanks'. Solids or dense materials like stones, dust particles, debris are removed by gravity force in this unit, and other less dense particles are carried to the next tank.

b) **Aeration:** In this method of water treatment, the air is made to circulate through the water to give it oxygen to increase its Bio-Oxygen Demand (BOD).

c) **Filtration:** Filtration is used for filtering out impurities present in wastewater. One of the most common filter used is sand filter.

3. Chemical Waste Water Treatment:

- Chemical waste water treatment involves the use of different strong chemicals to clean water.
- Chlorination is done by using chlorine (that acts as potent oxidising chemical) for treating the waste water to kill harmful bacteria.
- Ozone is also an oxidizing disinfectant that works to destroy viruses and harmful bacteria in the water.

- Neutralization method is used for treating industrial waste water. In this method, base or acid is mixed with water till it reaches the pH value of water. Generally, lime is used as a base to neutralize acidic water.

4.3.3 Advantages of Waste Water Treatment

NOTES

Waste water treatment has a number of benefits.

- Wastewater treatment ensures the release of pollutant/contaminant free water into lakes/streams/rivers.
- Waste water treatment helps in reducing the water pollution at surface level.
- Waste water treatment prevents the outbreak of water borne diseases.
- Water obtained from waste water treatment plants can be used for multiple purposes like human consumption/agricultural purposes/industrial use etc. This helps in the effective management of an essential natural resource, i.e., water.
- A lot of by-products released during treating water like methane gas can be used as source of energy.
- Recovered metal particles from the waste water treatment plant can be used effectively.

4.4 INLAND WATER CONSERVATION

'Inland Waters' are aquatic-influenced environments located within land boundaries. This includes those located in coastal areas, even those adjacent to marine environments. Inland water systems can be fresh, saline or a mix of the two (brackish water). Inland waters include lakes, rivers, ponds, streams, groundwater, springs, cave waters, floodplains, as well as bogs, marshes, and swamps, which are traditionally grouped as inland wetlands. The inland water include both fresh water masses and estuarine waters of varying salt content are clearly distinguishable from the salt waters of the oceans. The inland water masses are discrete and being isolated within the specific land area, acquire the characteristic chemical composition of the land, by exchange between soil and water.

Types of Inland Water

Frey (1960) has classified inland waters in three different ways.

(1) Whether the water is stationery (Lentic) or flowing (Lotic).

(2) Whether the water mass is natural or artificial.

(3) Whether the water mass is permanent / temporary.

(1) Lentic vs Lotic water

(a) Lentic Aquatic Systems

Those aquatic system which contains standing or stagnant water are referred to as Lentic aquatic systems. Lentic water systems are closed system which are generally formed in small or large depressions on earth's surface lacking any exit for the water to flow out. Natural processes in the long run transforms such a lentic body into a swamp or a marsh, a wetland and finally to dry land. For instance; ponds and lakes are familiar examples of such systems.

(b) The Lotic Aquatic Systems

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Lotic aquatic systems are those systems which contain flowing waters. For instance; springs, streams, and rivers are familiar examples of lotic systems. The primary function of these lotic bodies of water is to carry the surplus rain water back to the sea.

(2) Natural vs Artificial

a. Natural Bodies of Water

Certain parts of the world are gifted with plenty of natural waters serving human needs. For instance; natural ponds are perennial shallow water bodies. When a stream changes its course, it leaves behind an isolated body of standing water (lentic water) leading to the formation of natural pond. In limestone regions, depressions are created due to the solution of the underlying strata. The water gets accumulated in such depression either by floods or rainfall leading to the formation of natural ponds. Occasionally, a natural pond is created by the elimination of a lake whose basin (bottom) is never as deep as a lake.

b. Artificial Bodies of Water

According to man's needs water bodies are created artificially. It includes ponds, wells, tanks reservoirs etc. For instance; artificial ponds are results of anthropogenic or human activities like excavation, dam construction, etc. The water level of an artificial pond can be regulated by inflow and drainage.

Most of the fish ponds are semi artificial ponds.

Artificial water bodies can further be classified on the basis of construction method or construction material used for making the pond.

On the basis of construction method used artificial water bodies can be classified as:

- **Water Bodies Constructed by 'Dug out Method'**: These water bodies are constructed by excavating soil from an area to form a hole which gets filled by rain water, surface run-off, or groundwater.
- **Water Bodies Constructed by Embankment Method:** Embankment water bodies are formed by building one or more dikes above ground level to impound water. Such water bodies are usually drainable and fed by gravity flow of water or by pumping.
- **Water Bodies Constructed by Cut and Fill Method**: Cut and Fill water bodies are constructed by a mix of excavation and embankment on sloping ground.

On the basis of construction material used artificial water bodies can be classified as:

- **Earthen Water Bodies:** Earthen water bodies are the most common ones made up from soil materials.

- **Walled Water Bodies:** Walled water bodies are surrounded by blocks, bricks, or concrete walls. Sometimes wooden planking or corrugated metal is also used in the construction of walled water bodies.
- **Lined Water Bodies**: These are earthen water bodies only which are lined with an impervious materials like plastic or rubber sheet.

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(3) Temporary vs Permanent

Water bodies are divided into two general classes based on seasonal duration:

a. **Permanent Water Bodies**: Permanent water bodies are those which hold some water throughout the year.

b. **Temporary Water Bodies**: Temporary water bodies are those in which the basin have water in some seasons, however, it gets dry in others. Generally, three types of temporary water bodies are observed in temperate regions:

   (1) Spring or Vernal Water Bodies: Spring water body has water only in spring season.

   (2) Autumn Ponds or Vernal Autumn Water Bodies: Autumn water bodies dry up in summer while it is full of water in spring as well as autumn season.

   (3) Summer Water Bodies or Aestival: Water is present throughout the year in summer water bodies, however, during winters ice accumulates at the bottom in such water bodies.

4.4.1 Distribution of Inland Waters

Inland waters cover less than 2% of the earth's surface, approximately 2.5 x 106 km2. Lakes hold the major portion of the world's freshwater. Some regions are naturally bestowed with lakes and streams especially those regions once subjected to ancient glaciation. For instance; Canada and northern United States possess an immense supply of lakes, like the great lakes, which constitute the greatest body of freshwater on the globe. In India, majority of the wetlands are situated in the eastern parts of the country whereas, reservoirs and tanks have been created mainly for irrigation are distributed throughout the country. Large rivers and streams are well distributed in the northern and eastern region of the country. However, southern regions of the country also have a good number of inland waters. Many of them are seasonal in nature.

4.4.2 Origin of Inland Waters

Only a relatively small fraction of the total amount of water in the biosphere is found as free water on continental landmasses. The oceans holds approximately 97.6 percent of the biosphere's water, and polar ice, groundwater, and water vapour take up another 2.4 percent. Hence, less than 1 percent exists as continental free water, which we refer to as inland water. Even though, this is very low in percentage yet inland water is an essential element of the biosphere. It occurs in a wide variety of forms and is inhabited by a diverse set of biological communities, quite distinct from the communities of marine and terrestrial ecosystems. The basic origin of all inland water is ocean chiefly via the process of evaporation. This process is part of the global hydrologic cycle. A characteristic feature of this hydrological cycle is that more water evaporates from the ocean than it is directly precipitated back into it. The rest of the water vapour is precipitated back as rain, snow, or hail over continental landmasses.

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4.4.3 Importance of Inland Water and Wetlands

- Top of Form
- Inland water biodiversity supports the provision of most goods as well as services that freshwater ecosystems offer to people.
- Role of inland waters are diverse such as provision for food, fibre as well as medicines but also benefits such as pollution and nutrient absorption and recycling, flood management, drinking-water supply and mitigation against the impacts of natural catastrophes and climate change.
- As seen above, inland waters has high economic value.
- Similarly, wetlands have high economic value. Ecosystem services offered by wetlands include, recharge of aquifers, treatment of waste water and pollution abatement, general water quality improvement, habitats for fish, wildlife and several other animals and plant species, and biological productivity. In addition, wetlands are of high aesthetic and heritage value providing opportunities for recreation, research, and education.
- Wetlands have very diverse and productive environments. Wetlands serves as the major habitat for several species. For instance; freshwater wetlands accounts for 40% of the world's species and 12% of all animal species. Wetlands also acts as reservoir of genetic material for staple food like rice. Wetlands accounts for more than 20,000 medicinal plant species and almost 80% of the world's population depends upon it.
- Wetlands helps in floodwater storage as well as control. When water levels get very high due to excessive rainfall, the vegetation slows down the flow of water and stores part of it in the soil or in the surface which then reduces flooding as well as erosion downstream.
- The vegetation of wetlands serves as a sediment source that aids in holding together the banks of lakes, rivers, and beaches. Destruction of wetlands leads to problems like soil loss and sedimentation.
- Wetlands serves as a natural sewage system. The hydrophytes; specially adapted plants –helps in slowing down the percolation of water as well as purifying the water. The contaminants entering a wetland (like agrochemicals: pesticides, insecticides, fertilizers; human/animal excreta as well as industrial discharge) are separated and settle on the bottom. After this, they are absorbed by the plants and converted into essential nutrients for the proper growth and development of fauna. This protects the blockage and eutrophication of downstream water bodies.
- Thus, wetlands functions as natural filters and helps in controlling water pollution. Wetlands also serves as the source of replenishment to groundwater aquifers, which provide a large part of the drinking water worldwide.

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- Coastal wetlands act as buffer by absorbing huge amounts of wave and wind energy, thus reducing the damage caused inland.
- Wetlands prevents climate change in two ways: Firstly, they acts as carbon sinks, i.e., they store greenhouse gases, with approximations showing that wetlands especially peat and forested wetlands store as much as 40% of the global terrestrial carbon. Secondly, as mentioned above their ability to capture and purify water and their storm and wind buffering capacity can protect us from the deleterious effects of climate change like changing rainfall patterns, rising sea level, higher storm frequencies as well as in general extreme weather phenomena.
- Wetlands can yield products such as fish, shellfish, fruits, fuel, reed, rice, wood, meat, and several others at commercial levels.
- Wetlands also serves as major spots of tourism and recreation for general public as they are amazingly beautiful owing to their rich biodiversity. Wetlands can offer a range of sports like boating, fishing, or bird watching. They can serve best for educational tours as well as for carrying out some research activities.
- As discussed in the previous section, wetlands do have unique significance for both plant and animal kingdom including humans. Wetlands are essential not only for the locals who resides around them but also for the global supply of freshwater.

4.4.4 Major Threats to Inland Waters and Wetlands

Ever increasing human population as well as growing economic activity is the primary cause of loss of inland waters. Human pressures on quickly diminishing areas of inland waters resources are increasingly compromising many of the ecosystem services vital to the well-being of people as well as their economies. Habitat change, leading to the degradation as well as loss of inland water ecosystems and species, has been mainly determined by infrastructure development (like dams, dikes, and levees) or land conversion. The clearing, transformation or drainage for agricultural development is the chief cause of inland wetland loss worldwide.

Wetlands are the example of heavily impacted and degraded ecosystems. In the last hundred years only, we have lost almost half of the world’s wetland due to mismanagement and unnecessary human interference. Wetlands face a wide variety of threats owing to human activities. The major direct threats for inland wetlands are infrastructure development (like construction of roads, residential areas, construction of dams, commercial buildings etc.), land reclamation as well as over-harvesting. The chief indirect threats are setting up of aquaculture, agricultural activities, reduced water flow, depletion of ground and surface water supplies, introduction of invasive alien species, and organic and inorganic pollutants. In India, significant losses of wetlands have occurred due to urbanization, industrialization as well other agricultural and commercial activities. All these anthropogenic activities have led to hydrological perturbations and its numerous impacts, pollution and other consequences. All the above major threats to wetlands can also be divided as biotic and abiotic pressures as discussed below:

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Biotic Threats/Pressures

- Uncontrolled siltation and weed infestation.
- Uncontrolled discharge of waste untreated water from sewage as well as from industries leading to proliferation of aquatic weeds, which badly disturb the floral and faunal biodiversity.
- Similarly, uncontrolled surface run-off from agricultural fields containing agrochemicals like insecticides, pesticides or fertilizers can badly disturb the floral and faunal biodiversity.
- Excessive tree felling for industrial purposes as well as for obtaining fuel material can cause soil erosion thus affecting the rainfall pattern.
- Loss of several aquatic floral and faunal species due to water level fluctuation.
- Habitat destruction also leads to loss of fish and reduction in number of migratory birds.

Abiotic Threats/Pressures

- Extensive encroachment ensuing in shrinkage of area.
- Anthropogenic activities ensuing in habitat destruction as well as loss of floral and faunal biodiversity.
- Uncontrolled searching leading to changes.
- Hydrological intervention leading to loss of aquifers

4.4.5 Water Conservation Practices

Inland water system includes systems include large lakes, ponds, rivers, wetlands, streams, and seasonal vernal pools, etc. and provide several economically valuable commodities and services to society. Some of these services are:

(a) Flood control
(b) Transportation
(c) Recreation
(d) Purification of human and industrial wastes
(e) Serve as habitat for both plants and animals
(f) Fish and other food production

These ecosystem benefits have irreplaceable value and it is often impossible to achieve them when aquatic systems are degraded. Aquatic ecosystems can be protected or restored by recognizing the following:

- Rivers, lakes, wetlands, and their connecting ground waters are the 'Sinks' into which landscapes drain. Freshwater ecosystems are closely connected to the watersheds or catchments of which each is a part, and they are significantly affected by anthropogenic activities or alterations of land and water. The stream network itself is significant to the continuum of river processes.

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- Active patterns of flow that are sustained within the natural range of variation will help the integrity and sustainability of freshwater bodies.
- Further, freshwater system need that sediments and shorelines, heat and light properties, chemical and nutrient inputs, and plant and animal populations alter within natural ranges, neither experiencing excessive swings beyond their natural ranges nor being held at constant levels.

New policy and management steps will be required to protect aquatic ecosystems as well as their functions.

- Assess vulnerability of freshwater habitats to climate change impacts, like snow-melt, flood risk, dryer summers, as well as changing water levels and water quality earlier snow-melt, increased flood risk, or dryer summers. All these impacts vary from region to region and effective planning and management will be required to conserve them.
- If the currently protected habitats are likely to shift their range, consider the feasibility and value of extending the protected area's boundaries to include this new territory for species conservation.
- If species migration appears to be expected, work to eradicate barriers that may obstruct migration (e.g. dams).
- Increasing the quality of existing habitats by removing invasive plants, restoring native species, as well as protecting habitats from development and other stressors.
- Evaluating and protecting the health of recognized ecosystem services like stream buffers, which may benefit a stream or river from increased erosion of nearby land.
- Adopting management policy to determine whether the plans and policies are effective for achieving the conservation goals for a particular freshwater system.
- Sustenance mitigation policies as well as actions to reduce the potential extent of future climate change today.

To conclude, the effective management of inland waters require:

(a) Improved arrangements for river (or lake or aquifer)

(b) Basin–scale management

(c) Integrated marine and coastal area management

Factors that directly or indirectly affects inland waters should be taken into consideration before making policies. Ecological and economic benefits provided by inland waters must be taken into consideration by policy makers and decision makers. Good governance and effective implementation of conservation policy is necessary to ensure the long-term future of the services provided and supported by inland waters. A general awareness about the benefits of inland waters is need to be raised for implementing effective management.

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Check Your Progress

7. What are the parameters which needs to be taken into consideration before discharging water into a water body?
8. Why the pre-treatment is given to sewage water?
9. How neutralization method is used for treating industrial waste water?
10. How the wetlands prevent climate change?
11. What is the chief cause of inland wetland loss worldwide?

4.5 CAUSES OF POLLUTION OF AQUATIC RESOURCES AND THEIR MANAGEMENT

As seen in the previous section, water is essential not only in day-to-day life but also for industrial and commercial activities. However, water pollution is a serious concern which causes damaging effects to not only individual species or populations but also to natural communities. So, how do we define water pollution? Water pollution refers to the contamination of water bodies or aquatic bodies like groundwater, lakes, rivers, and oceans. Water pollution occurs when large amount of pollutants are discharged directly or indirectly into aquatic bodies without pre adequate treatment to remove harmful or toxic compounds. Figure 4.7 depicting various sources of water pollution

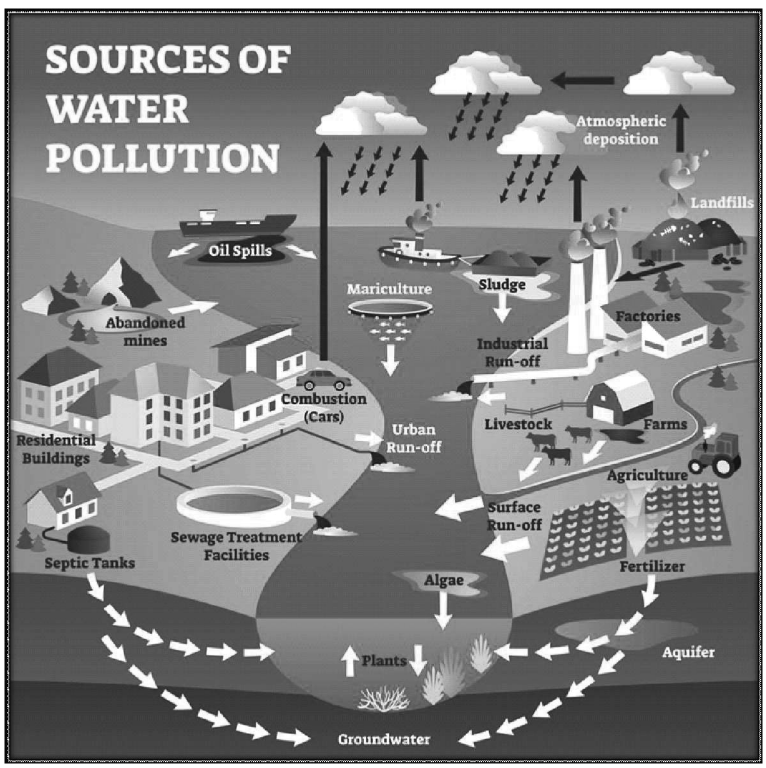

Fig. 4.7 Sources of Water Pollution

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A few water pollutants are listed below:

(1) Pathogens As Water Pollutants

Presence of infective agents in water is a matter of serious health concern. The list of a few infective agents that are present in aquatic bodies are as follows:

Infective agent Disease

(a) Viral : Viral hepatitis A Hepatitis E Poliomyelitis Rotavirus diarrhea in infants
(b) Bacterial : Typhoid fever Paratyphoid fever Bacillary dysentery, E. Coli. Diarrhoea Cholera
(c) Protozoal : Amoebiasis, Giardiasis
(d) Helminthic : Roundworm Threadworm Hydatid disease.
(e) Leptospiral : Weil's disease

(1) Chemical and Other Contaminants as Water Pollutants

Chemical contaminants may include organic as well as inorganic substances.

a) Organic water pollutants include

- Insecticides
- Pesticides
- Detergents
- Disinfectant used for disinfecting water (like chloroform)
- Food processing waste like fats and grease
- Petroleum hydrocarbons, including fuels (gasoline, diesel fuel, jet fuels, and fuel oil)
- Lubricants (motor oil), and fuel combustion by-products, from storm water run-off
- Industrial solvents (VOC's- volatile organic compounds)
- Debris from trees and bushes produced by logging operations
- Cosmetic products
- Several chemical compounds present in personal hygiene products

b) Inorganic water pollutants include:

- Pre-production industrial raw resin pellets.
- Heavy metals
- Chemical waste
- Acidity due to industrial discharges like sulphur dioxide.
- Slash and burn practices
- Fertilizers

The major sources of these water pollutants are as follows:

1. Sewage

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Discharging the drains and sewers in fresh water bodies leads to water pollution in cities.

2. Industrial Effluents

Discharge of industrial wastes containing toxic metallic salts, acids, phenols, cyanides, radioactive compounds, ammonia, are major sources of water pollution.

3. Synthetic Detergents

Household items like soaps and detergents used in bathing and cleaning also leads to water pollution.

4. Agrochemicals

Agrochemicals used in agricultural activities like NPK fertilizers (fertilizers containing nitrates, phosphates and potassium essential for plant's growth) and pesticides (insecticides, fungicides, herbicides, etc.) are the major source of both ground and surface water pollution.

5. Oil spills

Oil spillage into sea-water during drilling and shipment pollute it.

All these sources of water pollution can be divide into two categories:

(a) Point source pollution: Point source pollution refers to contaminants or harmful/toxic compounds that enter into aquatic bodies via a fixed source such as a pipe or ditch. For instance; discharges pipes from a sewage treatment plant of factories or several other organizations.

(b) **Non-point source pollution:** Non-point source (NPS) pollution resulting from diffuse sources in contrast to point source pollution. Nonpoint source pollution generally results from land runoff, precipitation, atmospheric deposition, drainage, seepage, or hydrological modification where tracing pollution to a single source becomes extremely difficult.

4.5.1 Types of Water Pollution

Water pollution can be divided into two categories

a. Groundwater Pollution

b. Surface water pollution

a. Groundwater Pollution

Groundwater refers to the water present beneath earth's surface in rock and soil pore spaces and in the fractures of rock formations. When a unit of rock or any unconsolidated deposit can yield a usable quantity of water, it is referred to as aquifer. The depth at which soil pore spaces or fractures and voids in rock become completely saturated with water is called the water table. Groundwater is used for

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a variety of household, industrial, and agricultural purposes. Groundwater remains connected to surface water like rivers, streams, and lakes. In fact, groundwater gets recharged from surface water only. Groundwater pollution refers to the change in the physical, chemical, and biological properties of groundwater due to contamination by chemicals, hazardous materials, chemicals, and other foreign particles. Groundwater can be polluted either via natural sources or man-made sources.

Natural sources of groundwater pollution like mineral deposit in rocks are less harmful when compared to toxic/hazardous compounds generated by different anthropogenic activities. These toxic compounds can easily seep from surface to ground depending upon the chemical type, soil porosity, and hydrology. However, the major source of groundwater pollution are industries. When the waste water from the industries is discharged directly into aquatic bodies without pre-treatment, it ultimately results in groundwater pollution. Agricultural activities also lead to groundwater pollution. A lot of different fertilizers, pesticides, and chemicals are used while farming. Some of these harmful substances seeps downwards along with the rainwater, thus contaminating groundwater. Residential areas also generate pollutants like pathogenic microorganisms as well as organic compounds leading to groundwater contamination.

Even though, groundwater pollution cannot be prevented completely yet even an individual can contribute in several ways to reduce groundwater pollution. A few guidelines for effectively managing or reducing the groundwater pollution are as follows-

- Proper disposal of household waste.
- Waterproof storage of household chemicals like paints, medicines, soaps, and detergents.
- Agricultural chemicals like fertilizers, pesticides, etc. should be properly stored to avoid leaching.
- Proper installation of septic system in the residential areas.
- Regular cleaning of the septic tanks will reduce groundwater contamination.

Treatment of contaminated groundwater is very costly and time-consuming affair. Hence, every possible measure should be taken to minimize the risk of groundwater pollution. Local public awareness programs and talks should be held regularly to convey the message regarding importance of groundwater as well as ways to minimize its contamination.

b. Surface Water Pollution

Lakes, rivers, streams, oceans, etc., are the natural water resources present on the exterior of the earth's crust. Surface water pollution refers to the change in the physical, chemical, and biological properties of surface water (lakes, rivers, streams, and oceans) due to contamination by chemicals, hazardous materials, and other foreign particles. Figure 4.8 depicting various point and non-point sources of water pollution.

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Fig. 4.8 *Various Point and Non-Point Sources of Water Pollution*

4.5.2 Effect of Water Pollution

Water pollution affects the physical, chemical and biological characteristics of water making it highly unfit for human consumption and also leads to severe diseases. The next section deals with the harmful effects of water pollution.

1. Change in Turbidity of the Polluted Water

Turbidity in water is caused mainly by human activities in certain industries, such as mining and agriculture that cause the movement of particles and get mixed up with water. Those can be mud, sand, and other waste materials found in the changing environment. Further, the material that increases the turbidity of water includes slit, tiny organic matter, inorganic material, clay, plankton, dissolved matter as well as other microscopic organisms. Higher turbidity makes the water cloudy or opaque. In fact, turbidity of the water is an indicator of potential pollution present in the water bodies. Excessive turbidity, cloudiness or opaqueness in drinking water is not only unappealing, but also unhealthy. High turbidity can provide habitat for pathogens which may lead to outbreak of water borne diseases. Figure 4.9 is depicting change in the turbidity of water**.**

Fig. 4.9 *Change in the Turbidity of Water*

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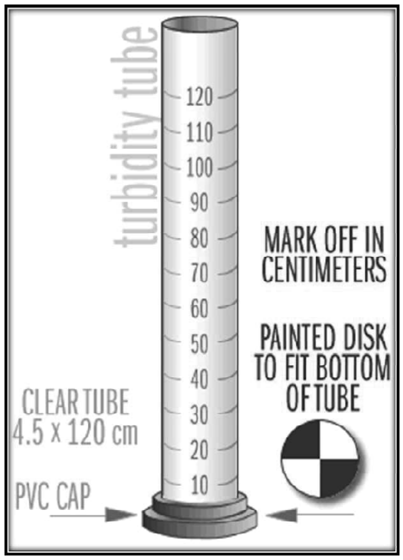

Fig. 4.10 *Turbidity Rod.*

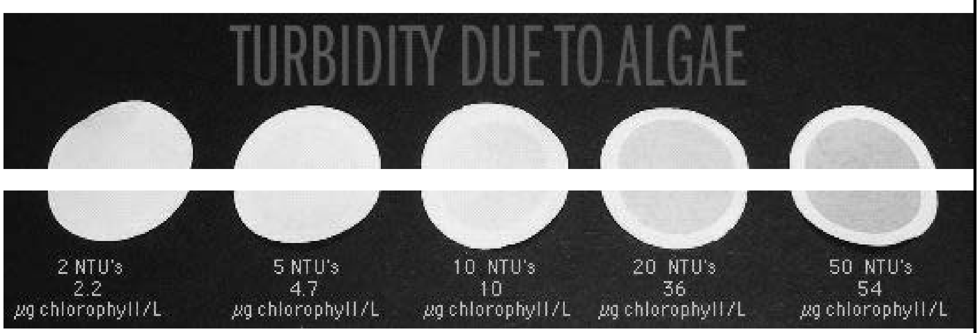

Fig. 4.11 *Change in Turbidity of Freshwater Due to the Presence of Sediment and algae*

Figure 4.10 is depicting the turbidity rod. Figure 4.11 depicting the change in turbidity of freshwater due to the presence of sediment.

Source of Figure- http://www.waterontheweb.org/under/waterquality/turbidity.html

2. Change in Colour of the Polluted Water

Water is a colourless liquid. The colour of the water is due to the presence of suspended particles as well as organic matter in it. For example greenish colour of pond water is due to the presence of organic substance or algae in it. The standard unit of colour is that which is produced by one milligram of platinum cobalt dissolved in one litre of distilled water. Tintometer is a kind of visual colour measuring instrument. It measures colour scale unit which is an international acknowledged specific colour method as a standard to measure the colour of liquid, solid, gelatin, and powder samples. Figure 4.12 is depicting the tintometer.

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Fig. 4.12 *Tintometer*

3. Change in Taste and Odour of the Polluted Water

Water is tasteless and odourless liquid. The taste or odour of a particular water sample is due to the presence of inorganic or organic substance present in it. Presence of inorganic material gives earthy smell to water whereas dead and decaying organic matter gives foul smell to water.

4. Change in Temperature of the Polluted Water

Temperature of surface water varies from space and time due to changing atmospheric conditions whereas that of ground water fluctuates with depth. Waste heat released from industrial effluents increases the temperature of water bodies and affects not only the distribution but also the survival of sensitive aquatic species.

5. Change in Total Dissolved Solids (TDS) of the Polluted Water

Total dissolved solids present in water can be determined by evaporating a sample of water and then weighing the dry residue left on the filter paper. TDS is measured in ppm or mg/l. The amount of TDS in water determines its suitability for our consumption. Table below depicts how the quality of water changes with the TDS values. Figure 4.13 is depicting the TDS value of polluted water.

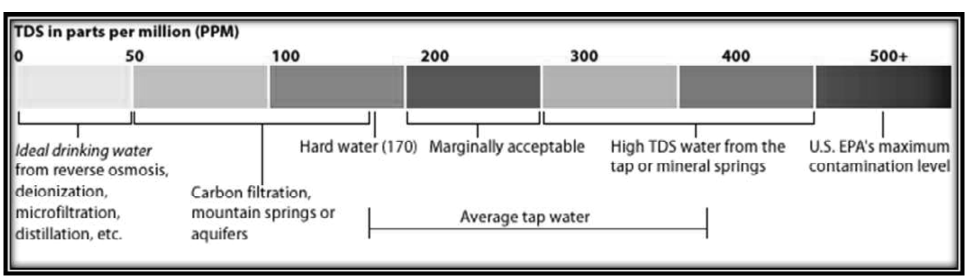

Fig. 4.13 *TDS Value of Polluted Water*

6. Change in pH Value of The Polluted Water

The pH value of pure water is 7, i.e., pure water is neutral.

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Water is considered to be acidic if pH value is less than 7, however, it is said to be alkaline if pH value is greater than 7. The range of pH value varies from 0 to 14. The alkalinity is caused by the presence of bicarbonate of calcium and magnesium or by the carbonates of hydroxides of sodium, potassium, calcium, and magnesium. Some, but not all of the compounds that cause alkalinity also cause hardness. The pH value is measured by using pH meters. Permissible pH value for public supplies may range in between 6.6 to 8.4. Figure 4.14 shows the change in pH value of the freshwater system affects its biotic communities**.**

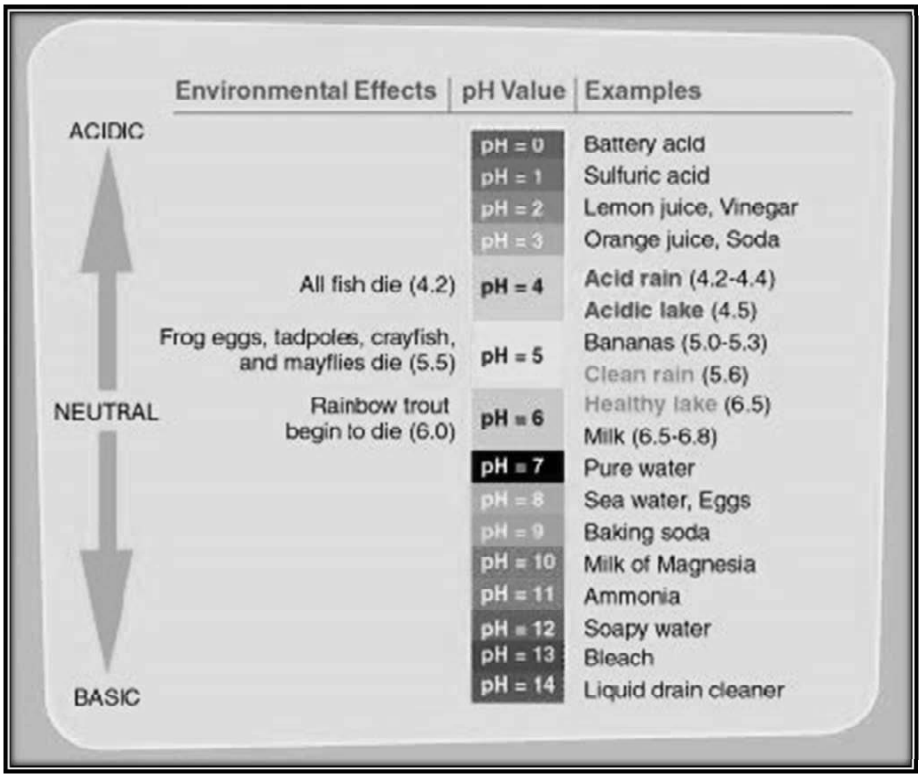

Fig. 4.14 *Effects of pH on Biotic Communities*

7. Change in Hardness of the Polluted Water

Hard water is generally undesirable, as they may lead to consequences like more soap consumption, making food tasteless, causing corrosion, skin hardening, scaling of boilers, incrustation of pipes, etc. Temporary hardness of the water can be simply removed by boiling it or by adding lime water to it. The bicarbonates and carbonates of calcium and magnesium are usually responsible for causing temporary hardness in water. Temporary hardness is also known as carbonate hardness. Carbonate hardness is equal to the total hardness or alkalinity; whichever is less. Permanent hardness of water cannot be removed by simply boiling it. The sulphates, chlorides, and nitrates of calcium or magnesium are responsible for causing the permanent hardness in water. Permanent hardness is also known as non-carbonate hardness. Non-carbonate hardness is the total hardness in excess of the alkalinity. If the alkalinity is equal to or greater than the total hardness, there is no non-carbonate hardness. Figure 4.15 is depicting water hardness scale.

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Water Hardness Scale		
Grains/Gallon	mg/L & ppm	Classification
Less than 1	Less than 17.1	Soft
1 to 3.5	17.1 to 60	Slightly hard
3.5 to 7.0	60 to 120	Moderately hard
7.0 to 10.5	120 to 180	Hard
10.5 and over	180 and over	Like a stone
Note - one grain per gallon = 17.1 parts per million (ppm)		

Fig. 4.15 *Water Hardness Scale*

8. Increased Nitrogen Content of Polluted Water Can Cause Methemoglobinemia

Nitrogen can be present in water in different forms like free ammonia, organic matter, nitrites or nitrates. Presence of nitrites in water proves to be highly dangerous. On the other hand, large amount of nitrates in the water can cause disease like blue baby disease or methemoglobinemia.

9. Increased Salinity of Polluted Water

Salinity of water occurs due to the presence of sodium and chloride ions in water. Excess salinity can make the water unfit for human consumption as saline water leads to severe dehydration.

10. Increase in The Amount of Trace Elements Present in Polluted Water

Mostly aluminium, arsenic, barium, bromide, cadmium, chromium, cobalt, copper, lead, zinc, nickel, phosphate, silver, tin, and vanadium. Some of the trace elements are essential for growth of living beings whereas others are dangerous or toxic to health and has the potential to cause severe health implications.

11. Polluted Water Can Cause Fluorosis

Fluoride pollution can cause serious defects in teeth as well as bones, a disease called as fluorosis.

12 Arsenic Pollution

Arsenic pollution can cause significant damage to the liver and the nervous system.

13. Lead and Mercury Poisoning

Some industrial effluents like mercury and lead can cause serious nervous disorders. Further, lead poisoning affects kidneys and reproductive system, liver, brain, and central nervous system. It also causes anaemia and mental retardation in children.

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14. Asbestos

This pollutant is a serious health hazard and carcinogenic. Asbestos fibres can be inhaled and cause illnesses such as asbestosis, mesothelioma, lung cancer, intestinal cancer, and liver cancer.

15. Petrochemicals

This is formed from gas or petrol released into water and can be toxic to marine life.

16. Water Pollution Leads to Bioaccumulation and Biomagnification

The phenomenon of bioaccumulation refers to the entry of a pollutant or toxic/ hazardous substance in the food chain while In bioaccumulation, the concentration of the toxic substance increases in the organism of same type as the toxic substance is retained in the body of the organism while in biomagnification, the toxic substance gets accumulated in the body of organisms at successive trophic levels at a higher concentration than the previous trophic level.

For example the classic case of DDT pesticides. It is a non-biodegradable chemical. When DDT enters aquatic bodies (like lakes, streams, rivers, etc.), it gets incorporated in the food chain and build up in the body of fishes. This step is known as bioaccumulation. As the fishes are eaten up by the animals of higher trophic levels, concentration of DDT keeps on increasing at each successive trophic level and this is referred to as biomagnification. Figure 4.16 depicting the difference in bioaccumulation and biomagnification.

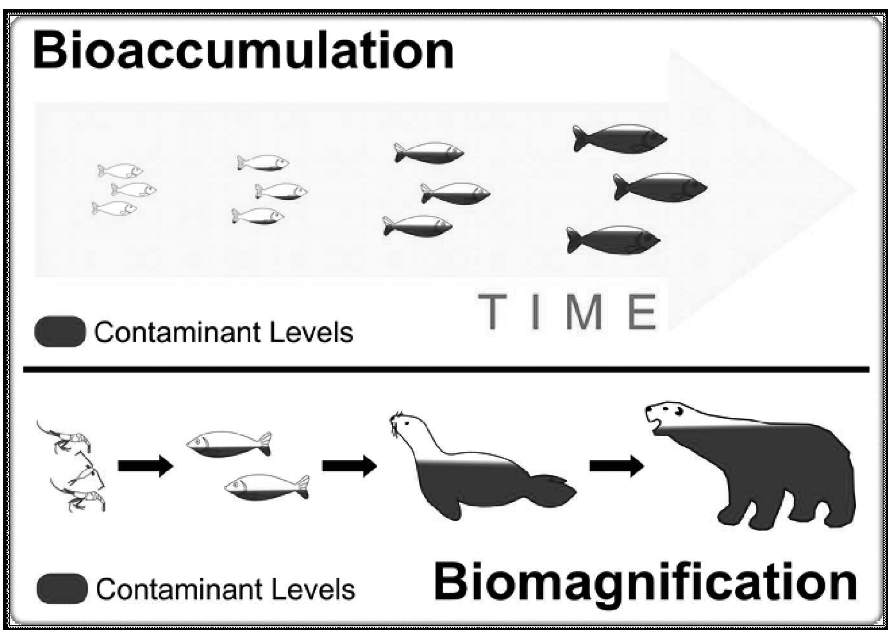

Fig. 4.16 *Bioaccumulation and Biomagnification*

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17. Dissolved Organic Matter Leads to Low Oxygen Saturation of Water

Oxygen gas is absorbed by the water from the atmosphere but it is being consumed by organic matter present in it. Therefore, if the oxygen gas present in water is lower than its normal saturation level, it indicates the presence of organic matter which makes the water unsuitable for consumption.

18. Eutrophication

Eutrophication refers to the process in which a water body becomes overly enriched with nutrients, leading to excessive growth of algae and planktons. The excessive growth (or bloom) of algae and plankton in a water body are indicators of this process. Eutrophication is considered to be a serious environmental matter as it often leads to the deterioration of water quality and the depletion of Dissolved Oxygen (DO) in aquatic bodies. Eutrophic water can eventually become 'dead zones' that are no longer capable of supporting aquatic life (both plants and animals). Over a period of time, anthropogenic activities like use of excessive fertilizers in agricultural field, disposal of nutrient rich waste into water bodies, etc. has increased the nutrient content of freshwater bodies ultimately leading to the deterioration of water quality and making it unfit for human consumption.

19. Oils Spills Affects The Floral and Faunal Diversity

Oil spills leads to the formation of a thick layer of oil on the surface of water. This thick oil layer can stop marine plants from receiving enough light for carrying out the process of photosynthesis as well as it can disturb the free flow of oxygen in the water. This severely affects the floral and faunal biodiversity. Figure 4.17 is depicting the devastating effect of oil spill.

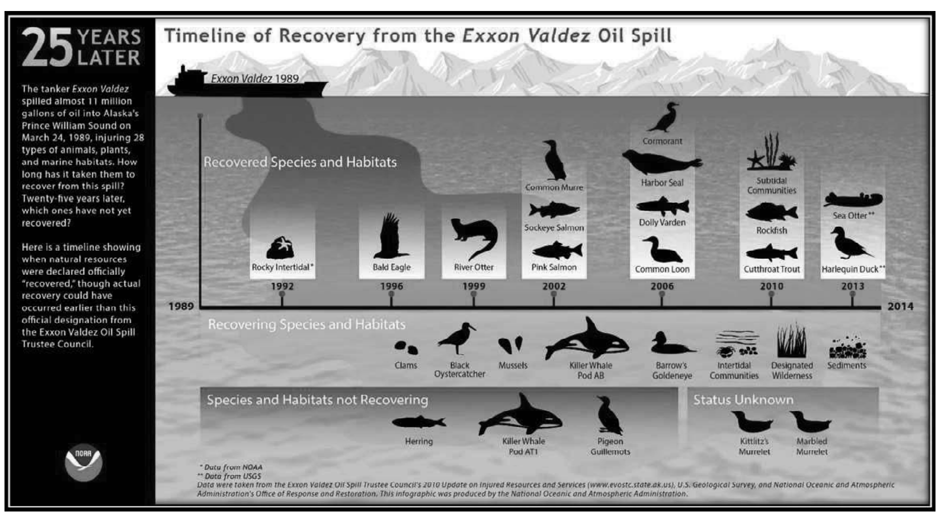

Fig. 4.17 *Devastating Effect of Oil Spill*

Source of Figure- *NOAA*

20. Pollute Water Has Increased Biological Oxygen Demand (BOD)

A lot of factors influence the BOD of water like temperature, pH of the water sample, inorganic substance present in the water, kind of aerobic microorganisms present in water, amount and type of organic matter present in the water sample,

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etc. BOD values indicate the polluting potential of water. BOD value of less than 1mg/L indicates pure drinking water, BOD value between 2-8mg/L indicates moderately polluted water, whereas a BOD value greater than 8mg/L indicates severely polluted water unfit for consumption. BOD finds its prime significance in sewage treatment plants. It indicates the respiration rate in sludge, soil, garbage etc.

21. Polluted Water Has Increased Chemical Oxygen Demand (COD)

COD measurements are important in accessing the quality of a given water body. COD values helps us to determine the extent of pollution that the water has undergone. COD tests also assess the amount of inorganic contaminants that is dissolved or suspended in a water body. Thus, it can be concluded that higher the COD, higher is the contamination level of water.

22. Microorganism and Planktons in Polluted Water

Water can support the growth several organisms. In some cases, it is advantageous as certain yeasts can provide good quality of bread and beer. However, some microorganisms are unhealthy and even life threatening. For instance; different kinds of microorganisms, bacteria, viruses, phytoplankton, zooplankton, etc. makes the water unfit for human consumption.

4.5.3 Management/Control of Water Pollution:

Adopting the following measures may help in reducing water pollution from non-point sources:

- Afforestation or planting trees would reduce pollution by sediments and will also prevent soil erosion.
- Proper disposal of household waste to prevent the contamination of both ground and surface water.
- Waterproof storage of household chemicals like paints, medicines, soaps, and detergents to prevent their seepage into groundwater.
- Agrochemicals like fertilizers, pesticide, and insecticides should be used judiciously and properly stored to avoid leaching.
- Use of nitrogen fixing plants to supplement the use of fertilizers.
- Adopting IPM (integrated pest management) techniques to reduce greater reliance on pesticides.
- Preventing run-off of manure. Diverting such manure run-off to basin for settlement will serve two purposes: firstly, it will prevent eutrophication (as discussed above), and secondly, nutrient rich water can be used as fertilizer in the fields.
- Proper installation of septic system in the residential areas to prevent leakage into groundwater.
- Further, regular cleaning of the septic tanks will reduce groundwater contamination.
- Separate drainage of sewage and rain water should be provided to prevent overflow of sewage with rain water.

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Adopting the following measures may help in reducing water pollution from point sources:

Sewage is created by residential, institutional, commercial as well as industrial establishments which includes household waste liquid from toilets, baths, showers, kitchens, sinks and so forth that is disposed of via sewers. In several areas, sewage also includes liquid waste from industry. Sewage can be effectively treated at the point where it is created like in septic tanks or it can be collected and transported via a network of pipes and pump stations to a municipal treatment plant. For managing/ controlling water pollution from point sources (like sewage), treatment of waste water is essential before being discharged into aquatic bodies. Parameters which needs to be taken into consideration before discharging water are: Total solids, Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), nitrates and phosphates, oil and grease, toxic metals, etc. Waste waters should be properly treated by primary, secondary and tertiary treatments to reduce the BOD, COD levels up to the permissible levels before discharging them into aquatic bodies.

4.6 WETLANDS- PROBLEMS AND MANAGEMENT

Wetlands are referred to as the ecotones or transitional zones between permanently aquatic and dry terrestrial ecosystems. According to Ramsar Convention (Article 1.1), wetlands are "Areas of marsh, fen, peat-land, or water, whether natural or artificial, permanent or temporary with water that is static or flowing, fresh, brackish, or salt, including areas of marine water the depth of which at low tide does not exceed six meters". In addition, for the purpose of protecting the coherent sites, the article 2.1 provides that wetlands to be included in the Ramsar list of internationally important wetlands: "may incorporate riparian and coastal zones adjacent to the wetlands, and islands or bodies of marine water deeper than six metres at low tide lying within the wetlands".

A wide variety of wetlands like marshes, swamps, open water bodies, mangroves, tidal flats, salt marshes, etc., exists in our country. Wetlands are vital to maintain a healthy environment. A few characteristics of wetlands are as follows:

- Wetlands helps to retain water during dry periods, accordingly keeping the water table high and relatively stable.
- During floods, they act to reduce flood levels and to trap suspended solids and nutrients to the lakes than if they flow directly into the lakes.
- When compared to tropical rain forests and coral reefs, wetlands are outstanding in their biological productivity.
- Wetlands are generally more diverse and unique in structure, characteristics and functions, when compared to other ecosystems.
- Wetland ecosystem exhibits high species richness and species diversity.
- Wetlands are often dynamic and complex.
- Wetlands are under the influence of an array of biotic as well as abiotic factors.

- However, the unique feature that determines the nature of a wetland is its hydrologic regime. Hence, even a minor change in the hydrologic regime of wetland ecosystem leads to drastic change in its species richness, composition, trophic relations as well as productivity.

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Ramsar Wetland Type Classification:

Under the Ramsar convention, a broad classification of wetlands has been defined to help in rapid identification of wetland at each Ramsar site. The codes used in the text below are based upon the Ramsar Classification System for Wetland Type as approved by recommendation 4.7 and amended by resolutions VI.5 and VII.11 of the Conference of the Contracting Parties. As shown in the classification below, wetlands have been divided into three major categories with several subdivisions.

(1) Marine/Coastal Wetlands

- Permanent shallow marine waters in most cases less than six metres deep at low tide; includes sea bays and straits.
- Marine sub-tidal aquatic beds includes kelp beds, sea-grass beds, and tropical marine meadows.
- Coral reefs.
- Rocky marine shores includes rocky offshore islands, sea cliffs.
- Sand, shingle or pebble shores; includes sand bars, spits and sandy islets; includes dune systems and humid dune slacks.
- Estuarine waters permanent water of estuaries and estuarine systems of deltas.
- Intertidal mud, sand or salt flats.
- Intertidal marshes includes salt marshes, salt meadows, saltings, raised salt marshes; includes tidal brackish and freshwater marshes.
- Intertidal forested wetlands includes mangrove swamps, nipah swamps and tidal freshwater swamp forests.
- Coastal brackish/saline lagoons brackish to saline lagoons with at least one relatively narrow connection to the sea.
- Coastal freshwater lagoons includes freshwater delta lagoons.
- Karst and other subterranean hydrological systems, marine/coastal.

(2) Inland Wetlands

- Permanent inland deltas.
- Permanent rivers/streams/creeks; includes waterfalls.
- Seasonal/intermittent/irregular rivers/streams/creeks.
- Permanent freshwater lakes (over 8 ha); includes large oxbow lakes.
- Seasonal/intermittent freshwater lakes (over 8 ha); includes floodplain lakes.
- Permanent saline/brackish/alkaline lakes.
- Seasonal/intermittent saline/brackish/alkaline lakes and flats.

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- Permanent saline/brackish/alkaline marshes/pools.
- Seasonal/intermittent saline/brackish/alkaline marshes/pools.
- Permanent freshwater marshes/pools; ponds (below 8 ha), marshes and swamps on inorganic soils; with emergent vegetation water-logged for at least most of the growing season.
- Seasonal/intermittent freshwater marshes/pools on inorganic soils; includes sloughs, potholes, seasonally flooded meadows, sedge marshes.
- Non-forested peatlands; includes shrub or open bogs, swamps, fens.
- Alpine wetlands; includes alpine meadows, temporary waters from snowmelt.
- Tundra wetlands; includes tundra pools, temporary waters from snowmelt.
- Shrub-dominated wetlands; shrub swamps, shrub-dominated freshwater marshes, shrub carr, alder thicket on inorganic soils.
- Freshwater, tree-dominated wetlands; includes freshwater swamp forests, seasonally flooded forests, wooded swamps on inorganic soils.
- Forested peat lands; includes peat swamp forests.
- Freshwater springs; includes oases.
- Geothermal wetlands.
- Karst and other subterranean hydrological systems, inland

Note: "floodplain" is a broad term used to refer to one or more wetland types, which may include examples from the Ramsar wetland type classification, or other wetland types. Some examples of floodplain wetlands are seasonally inundated grassland (including natural wet meadows), shrublands, woodlands, and forests. Flood plain wetlands are not listed as a specific wetland type herein.

(3) Human-made wetlands

- Aquaculture (e.g., fish/shrimp) ponds
- Ponds; includes farm ponds, stock ponds, small tanks; (generally below 8 ha).
- Irrigated land; includes irrigation channels and rice fields.
- Seasonally flooded agricultural land (including intensively managed or grazed wet meadow or pasture).
- Salt exploitation sites; salt pans, salines, etc.
- Water storage areas; reservoirs/barrages/dams/impoundments (generally over 8 ha).
- Excavations; gravel/brick/clay pits; borrow pits, mining pools.
- Wastewater treatment areas; sewage farms, settling ponds, oxidation basins, etc.
- Canals and drainage channels, ditches.
- Karst and other subterranean hydrological systems, human-made.

Ramsar classification simplifies the portrayal of wetlands by dividing it based on geographic location and human parameters, however, the fact that overlaps happen since the categories are not always mutually exclusive. Thus, a more in depth classification divides wetlands into five major categories namely:

1) Marine wetlands (coastal wetlands including coastal lagoons, rocky shores, and coral reefs)
2) Estuarine wetlands (including deltas, tidal marshes, and mangrove swamps)
3) Lacustrine wetlands (wetlands associated with lakes)
4) Riverine wetlands (wetlands related to rivers and streams)
5) Palustrine wetlands (meaning 'Marshy' – marshes, swamps and bogs)

4.6.1 Ecological Importance of Wetlands

Ecosystem services offered by wetlands include, recharge of aquifers, treatment of waste water and pollution abatement, general water quality improvement, habitats for fish, wildlife and several other animals and plant species, and biological productivity. In addition, wetlands are of high aesthetic and heritage value providing opportunities for recreation, research, and education.

1. Wetlands Have Very Diverse and Productive Environments.

Wetlands serves as the major habitat for several species. For instance; freshwater wetlands accounts for 40% of the world's species and 12% of all animal species. Wetlands also acts as reservoir of genetic material for staple food like rice. Wetlands accounts for more than 20,000 medicinal plant species and almost 80% of the world's population depends upon it.

Algae are chief part of a wetland ecosystem. Algae supply food for animals like small fish, insects and invertebrates. There are four main types of hydrophytes (plants that only live in or on water) in a wetland System. Submerged, floating, emergent shrubs and various amphibious trees.

- **Submerged Water Plants**: Submerged water plants are not rooted in the substrate and floating beneath the surface i.e. they are completely submerged in water.
- **Emergent Water Plants**: Emergent water plants are rooted in the substrate, however their leaves and flowers extends into the air. They are present near the shoreline.
- **Floating-leaved Water Plants**: Floating-leaved water plants are rooted in the substrate but with floating leaves. Their roots can easily suck nutrients.

The surrounding plants as well as shrubs make up the swamp area that surrounds the wetland, usually in soils with a high saturated water level. These plants are adapted to wet conditions and hence can sustain life with a fair amount of water in their cells.

Depending upon the wetland sediments, invertebrates can reach high densities (over 100,000 per square meter), they may be substantial drivers of wetland biogeochemical processes. For instance, growing evidence suggests that aquatic invertebrate activity can enhance greenhouse gases emissions. For example; the

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burrows of midge larvae emit high concentrations of nitrous oxide. The main animals found in a wetland include fish, amphibians, reptiles, mammals, and monotremes (mammals that lay eggs). A few wetlands are capable of sustaining thousands of species of animals Fauna in a wetland help maintain the flora in a wetland eating and re-pollinating all the plants.

2. Flood Protection

Wetlands helps in floodwater storage as well as control. When water levels get very high due to excessive rainfall, the vegetation slows down the flow of water and stores part of it in the soil or in the surface which then reduces flooding as well as erosion downstream.

3. Soil Erosion

The vegetation of wetlands serves as a sediment source that aids in holding together the banks of lakes, rivers and beaches. Destruction of wetlands leads to problems like soil loss and sedimentation.

4. Maintenance of Water Quality and Pollution Control

Wetlands serves as a natural sewage system. The hydrophytes; specially adapted plants, helps in slowing down the percolation of water as well as purifying the water. The contaminants entering a wetland (like agrochemicals, pesticides, insecticides, fertilizers; human/animal excreta, as well as industrial discharge) are separated and settle at the bottom. After this, they are absorbed by the plants and converted into essential nutrients for the proper growth and development of fauna. This protects the blockage and eutrophication of downstream water bodies.

Thus, wetlands functions as natural filters and helps in controlling water pollution. Wetlands also serves as the source of replenishment to groundwater aquifers, which provide a large part of the drinking water worldwide.

5. Storm and Wind Buffer

Coastal wetlands act as buffer by absorbing huge amounts of wave and wind energy, thus reducing the damage caused inland.

6. Climate Change Mitigation and Adaptation

Wetlands prevents climate change in two ways; firstly, they acts as carbon sinks, i.e., they store greenhouse gases, with approximations showing that wetlands; especially peat and forested wetlands store as much as 40% of the global terrestrial carbon. Secondly, as mentioned above their ability to capture and purify water and their storm and wind buffering capacity can protect us from the deleterious effects of climate change like changing rainfall patterns, rising sea level, higher storm frequencies as well as in general extreme weather phenomena.

Wetland Products

Wetlands can yield products such as fish, shellfish, fruits, fuel, reed, rice, wood, meat, and several others at commercial levels.

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Recreation and Tourism

Wetlands also serves as major spots of tourism and recreation for general public as they are amazingly beautiful owing to their rich biodiversity. Wetlands can offer a range of sports like boating, fishing or bird watching. They can serve best for educational tours as well as for carrying out some research activities.

As discussed in the previous section, wetlands do have unique significance for both plant and animal kingdom including humans. Wetlands are essential not only for the locals who resides around them but also for the global supply of freshwater.

4.6.2 Major Threats to Wetlands

Wetlands are the example of heavily impacted and degraded ecosystems. In the last hundred years only, we have lost almost half of the world's wetland due to mismanagement and unnecessary human interference. Wetlands face a wide variety of threats owing to human activities. The major direct threats for inland wetlands are infrastructure development (like construction of roads, residential areas, construction of dams, commercial buildings, etc.), land reclamation, as well as over-harvesting. The chief indirect threats are setting up of aquaculture, agricultural activities, reduced water flow, depletion of ground and surface water supplies, introduction of invasive alien species, and organic and inorganic pollutants. In India, significant losses of wetlands have occurred due to urbanization, industrialization as well other agricultural and commercial activities. All these anthropogenic activities have led to hydrological perturbations and its numerous impacts, pollution and other consequences. All the above major threats to wetlands can also be divided as biotic and abiotic pressures as discussed below:

Biotic Threats/Pressures

- Uncontrolled siltation and weed infestation.
- Uncontrolled discharge of waste untreated water from sewage as well as from industries leading to proliferation of aquatic weeds, which badly disturb the floral and faunal biodiversity.
- Similarly, uncontrolled surface run-off from agricultural fields containing agrochemicals like insecticides, pesticides, or fertilizers can badly disturb the floral and faunal biodiversity.
- Excessive tree felling for industrial purposes as well as for obtaining fuel material can cause soil erosion thus affecting the rainfall pattern.
- Loss of several aquatic floral and faunal species due to water-level fluctuation.
- Habitat destruction also leads to loss of fish and reduction in number of migratory birds.

Abiotic Threats/Pressures

- Extensive encroachment ensuing in shrinkage of area.
- Anthropogenic activities ensuing in habitat destruction, as well as loss of floral and faunal biodiversity.

- Uncontrolled searching leading to changes.
- Hydrological intervention leading to loss of aquifers

4.6.3 Wetland Management

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'Ramsar Convention' is a convention on wetlands that was signed in the year 1971 in the Iranian city of Ramsar. The discussions for the convention began in the year 1960s by different countries and NGOs for the protection of wetland habitats of migratory waterbirds. Finally, it came into force in the year 1975. The main features of 'Ramsar Convention' are as follows:

- 'Ramsar Convention' is the only international treaty that addresses the concerns of a specific ecosystem, i.e., wetland.
- Originally, the idea of the 'Ramsar Convention' is focused on the conservation of the habitats for water birds.
- The official name of the treaty is 'The Convention on Wetlands of International Importance' especially as Waterfowl Habitat.
- Over a period of time, this treaty has widened its prospects and covers all aspects of wetland conservation.

The three major pillars of 'Ramsar Convention' are as follows:

- **Wise Use**: To work towards the wise use of all wetlands.
- **List of Wetlands of International Importance**: To designate suitable wetlands for the list of wetlands of international importance, and to ensure their effective management.
- **International Cooperation** To bring cooperation internationally over the transboundary wetlands, shared wetland systems, and shared species.

As of October 2020, there are two thousand four hundred six (2406) wetlands in the list of wetlands of international importance. It is not a regulatory regime. Ramsar Convention was altered by the Paris Protocol in 1982 as well as by the Regina Amendments in 1987.Montreux Record is launched in 1990 in associated with the Ramsar Advisory Mission. Montreux Record is basically a register of the list of those Ramsar Sites that require urgent attention.

World Wetlands Day was first celebrated in 1997 and from there onwards it was celebrated each year on 2nd February to mark the anniversary of the Ramsar Convention. The main aim of the World Wetlands Day is to promote its mission of protecting the wetlands.A conference of the contracting parties abbreviated as COP to the convention meets every three years.

The Ramsar Convention has six international organization partners:

- Birdlife International
- IUCN- International Union for Conservation of Nature
- Wetlands International
- WWF- World wide fund for nature
- International Water Management Institute
- Wildfowl and Wetlands Trust

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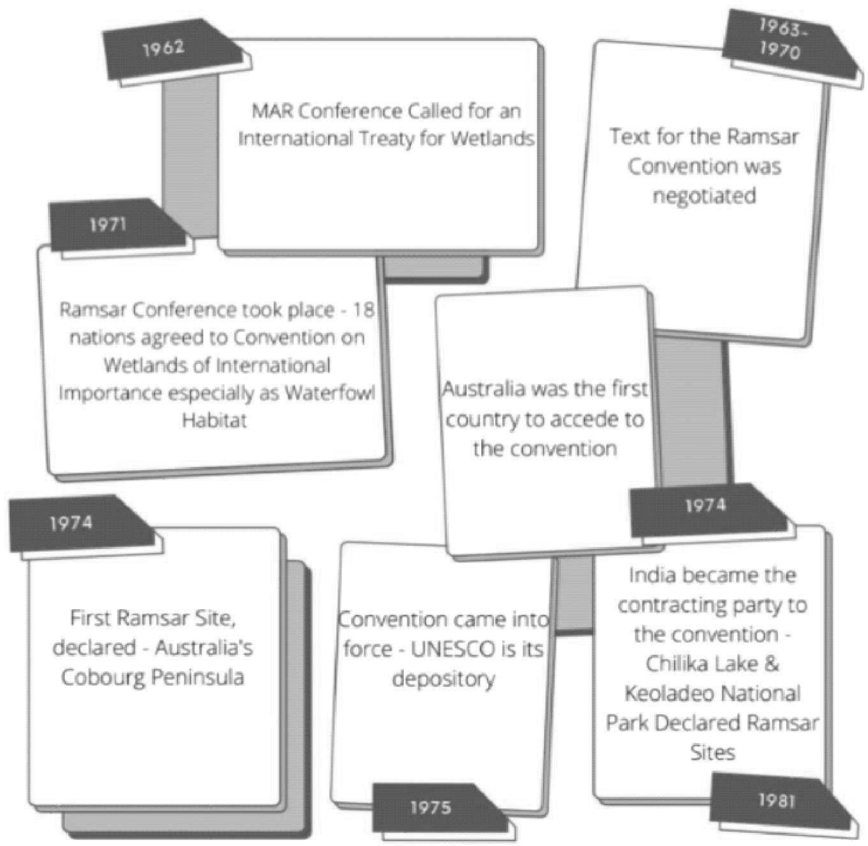
- The convention comes with a six-year strategic plan.
- The newest one is the 4th Ramsar Convention Strategic Plan 2016-2024 which was agreed upon at COP12 of the convention.
- Ramsar Convention's Standing Committee has 18 members in total that are elected at COP till the next COP elects new members.
- The Convention works in three languages: English, Spanish, and French.



India and Ramsar Conservation

India became a party to Ramsar Convention on 1st February 1981. India's innitiatives to conserve the national wetlands (4.63% of the total geographical area) are:

1. Wetlands (Conservation and Management) Rules, 2017

Constitution of State Wetland Authority: It has provisions for establishing a State Wetland Authority (SWA) in every state and Union Territory to be headed by the Environment Minister of the respective state. It includes expert in the fields of wetland ecology, socioeconomics, fisheries, hydrology, landscape planning, etc. They collectively will determine the 'wise use principle' that shall govern the management of wetlands. 'Wise use principle' refers to the principles of sustainable use that are compatible with conservation. This has led to the decentralization of powers.

Functions of State Wetland Authority (SWA):

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- SWA develop an inclusive list of activities to be regulated and permitted within notified wetlands and their zone of influence.
- SWA recommend supplementary forbidden activities for 'Ramsar sites' wetlands.
- It helps to define policies for improved use of wetlands.
- SWA recommend measures for wetland conservation.
- SWA also helps in raising awareness among its stakeholders as well local communities with respect to the significance of wetlands.
- SWA helps in setting up of National Wetland Committee, i.e., NWC.
- NWC will replace the Central Wetlands Regulatory Authority and shall be headed by the secretary to MoEFCC.

Importance of Centre for Wetland Conservation and Management (CWCM)

- The devoted Centre would help in addressing detailed research needs as well knowledge gaps.
- It would serve as a knowledge hub and helps in exchanging between State/ UT Wetland Authorities, policy-makers, managers, researchers, wetland users, as well as practitioners.
- Centre also helps in building partnerships and networks with appropriate national and international agencies.
- Centre aid in the application of integrated approaches for conservation, management, and wise use of the wetlands.
- Centre would also assist the national and State/UT Governments in the design and implementation of policy and regulatory frameworks, management planning, monitoring, and targeted research for wetlands conservation.

Purpose of National Wetland Committee (NWC)

The function of the National Wetland Committee (NWC) are:

- It aids in monitoring the implementation of rules.
- NWC advises the central government on appropriate policies as well as action programs for conservation and wise use of wetlands.
- NWC recommends designation of wetlands of international importance under the Ramsar Convention.
- Advice collaboration with international agencies on issues related to wetlands.
- NWC helps in setting up a digital inventory.
- Digital inventory is based upon the list of wetlands created by state authorities. This digital inventory is updated every 10 years.
- Prohibited activities: The rules forbid the release of undesirable waste from villages, towns, cities, industries, etc. It also prevents the solid waste dumping into the wetlands.

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- It also prohibits conversion of wetland area for non-wetland purposes as well as construction of a permanent structure on notified wetlands is banned.
- All these rules shall apply to wetlands notified by the State government, Central government, Union territory Administrations, and those classified as wetlands of international importance under the Ramsar convention.

2. The Ministry of Environment, Forest and Climate Change released a set of guidelines in January 2020 for implementation of the Wetland Rules 2017.
3. India regulates the following wetlands:
   a. Wetlands designated under the Ramsar list.
   b. Wetlands notified under central, state, and UT rules.
4. India does not regulate the following wetlands under Wetlands Rules:
   a. River channels
   b. Paddy fields
   c. Human-made water bodies constructed precisely for aquaculture purposes, constructed for drinking water purposes; salt production purposes; recreation purposes; as well as for irrigation purposes
   d. Wetlands falling within areas covered under the Indian Forest Act, 1927; Forest Conservation Act, 1980; and State Forest Acts.
   e. Wetlands falling within areas covered under the Wildlife Protection Act, 1972.
   f. Wetlands falling within areas covered under the Coastal Regulation Zone Notification, 2011.

4.7 WATER BORNE HUMAN DISEASES

Infectious diseases spread from infected person to healthy ones via several routes like air, food, water etc. Water borne diseases are referred to as those diseases that spreads via drinking or using contaminated water. Water generally gets contaminated under poor hygienic or in-sanitary conditions. Contamination can occur either at the source of water supply, while passing through water pipes, which are broken, or at homes too when water is not stored properly. The water can be contaminated with either human or animal face's and the diseases transmitted by drinking such water are known as faeco-orally transmitted diseases. Water borne diseases can also be transmitted through eating food prepared using contaminated water or using utensils which have been washed with the contaminated water.

Sources of Infection

The two major source of infection areas follows.

1) **Drinking Water**: Drinking water can be contaminated via:
   - Contamination at its main source
   - Contaminated during supply or storage of the water
   - Ice made from contaminated water

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2) **Food**: Food can be contaminated via:
   - Contaminated during or after preparation of the food.
   - Using utensils washed with contaminated water for food preparation.
   - Fruits and vegetables, washed with contaminated water and eaten raw.
   - Using fruits and vegetables, grown at or near ground level and irrigated with water contaminated with human waste, and eaten raw.

Water-borne diseases are widespread in areas having-

- Insufficient supply of water
- Poor quality of water
- Problematic or badly laid sewage pipelines
- Poor sanitary conditions
- In remote villages where water from step wells or uncovered wells or ponds are used for multipurpose like bathing, washing clothes, as well as for drinking.
- Defecation in the open particularly near major source of drinking water.
- Poor system for the proper disposal of human waste
- Water-borne diseases can also occur if contaminated water is used for kitchen purpose like washing utensils or for washing fruits and vegetables especially when eaten raw.
- Water borne diseases can also be transmitted by using ice prepared with low quality water from unreliable sources.

Though, water borne diseases may occur in individuals throughout the year yet a seasonal increase is generally noted in specific season like summer, monsoon, or post-monsoon period. Over a period of time, it has been observed that the risk of large outbreaks of water-borne diseases surges following heavy rains.

4.7.1 Water Borne Diseases Caused By the Presence of an Infective Agent

Now we will discuss some common water borne diseases, their infectious agent, symptoms and prevention.

The common prevention measures for most of the diseases include the following, where as any specific prevention to be followed is discussed with the precise diseases.

- Prevention includes avoiding drinking any water that isn't bottled and sealed as well as avoiding eating food from street vendors.
- Prevention involves frequent hand washing with soap and water.
- Eating completely cooked food.
- Eating fruits and vegetables whose outer layer can be peeled off completely (like banana, oranges, avocado, etc.)
- Maintaining personal hygiene.

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1. Typhoid Fever

Infective Agent: *Salmonella typhi* (Bacteria)

- The bacilli are excreted in the urine and faeces in the acute stage of the disease and some patients may continue to excrete S.Typhi in the convalescent stage as well. A small percentage of the patients may become chronic carriers and excrete the bacilli for years. The incubation period is 2 weeks with a range of 7 to 21 days.

Symptoms: Symptoms include a fever that increases gradually**,** Malais, Lethargy Myalgia

Muscle aches, Fatigue, Sweating, Loss of appetite, Low pulse (Bradycardia), Diarrhea or constipation,Mental apathy and dullness.

Careful physical examination by a trained physician as well as blood culture for *Salmonella typhi* helps in detecting and treating typhoid fever.

Prevention and Treatment: Typhoid is treated with antibiotics. Vaccines are recommended for people whose job involves traveling in areas having poor sanitation. The vaccine can be taken via a shot or orally for a number of days.

2. Cholera

Infective Agent: *Vibrio cholerae* (Bacteria)

- Serogroup O1 and 0139- are responsible for causing cholera. *V.cholerae* O1 occurs as two biotypes namely classical and E1 Tor. Each biotype it also occurs as two serotypes namely Ogawa and Inaba. Nearly all the current cholera outbreak has been caused by the E1 Tor biotype. Man is the only host. Patients remain infectious usually for a few days after recovery from clinical symptoms. Occasionally, the carrier stage may persist for several months. The chronic carriers however do not play essential role in the spread of disease. *V.Cholerae* can survive for long periods in the environment and can live in association with certain aquatic plants and animals, making water an important reservoir for infection .Incubation period varies from a few hours to 5 days, usually 2-3 days.

Symptoms: Nausea, Vomiting, Diarrhea, Muscle cramps

Treatment: Cholera can be treated with antibiotics

3. Giardiasis

Infective Agent: *Giardia intestinalis* (Protozoa)

- This waterborne disease is transmitted via contaminated water of ponds or swimming pools or city water supply. The infection clears on its own after a few weeks. However, victims can experience intestinal problems for years to come.

Symptoms include: Abdominal pain, Cramps and bloating, Diarrhea, Nausea, Weight loss

Prevention: No vaccination is available for giardiasis. Swallowing water while swimming should be avoided.

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Treatment

- Doctors prescribe anti-parasitic and antibiotic medications for severe patients.

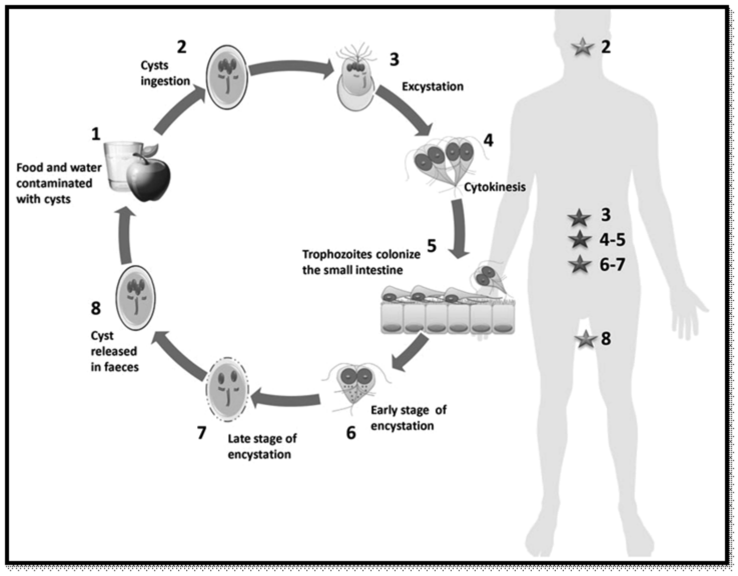

Fig 4.18 *Life Cycle of* Giardia Intestinalis

Figure 4.18 is depicting life cycle of *Giardia intestinalis*

4. Bacillus Dysentery

Infective Agents: Bacteria, viruses, or parasites in contaminated food and water

- Dysentery refers to as the diarrhoea with visible blood in the stools. Shigella is the most common cause of dysentery. *Shigella dysenteriae* 1 is often associated with severe disease and complications. Infections with two species of *Shigella,* i.e., *S. sonnei* and *S. flexneri* result in short clinical course and negligible mortality. As only a few bacilli are enough to transmit the infection, *Shigella* is usually transmitted via person to person. The patients may transmit the infection in the acute stage and up to one month after illness.Infection with *Entamoeba histolytica* presents with similar clinical symptoms, however, it is rare in young children. The incubation period is usually 1-3 days. Asymptomatic carriers may transmit infection to healthy individuals. The carrier state rarely persists for long periods.

Symptoms include: Abdominal cramps and pain, Diarrhea, Fever, Anorexia, Weight loss, Nausea, Vomiting, Dehydration

Treatment: Mild dysentery can be treated with rest and fluids. Over-the-counter medicines like Pepto-Bismol can help with stomach cramping. Severe cases can be treated with antibiotics.

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5. Viral Hepatitis

Infective Agent: Viral Hepatitis A, E

Viral hepatitis A and E are responsible for causing water borne disease. Major outbreak of viral hepatitis in India are due to Hepatitis E virus. Rare outbreaks of hepatitis A, may also occur. Although, outbreaks of hepatitis A are relatively rare, as by age five most young individuals gets through natural infection. Incubation period of hepatitis E is usually one to two months. Hepatitis E infection may be preceded by other water borne disease having shorter incubation periods like acute diarrheal diseases (few days) and typhoid fever (one to three weeks).

Symptoms: Fatigue, Weakness, Clay-colored bowel movements, Jaundice, Nausea and vomiting, Abdominal pain, especially near your liver, Abdominal cramps, Liver Inflammation, Loss of appetite, Sudden fever.

Prevention: Vaccination is the best possible way to prevent hepatitis A.

Treatment: Vaccinated person builds lifelong immunity. Take ample rest, avoid drinking alcohol, and drink plenty of fluids. The disease will run its course, and full recovery is expected after three months.

6. Salmonellosis

Infective Agent: *Salmonella enterica* and *Salmonella bongori*

Majority of the salmonella cases comes from ingesting water or food contaminated with faeces. Undercooked or raw food, such as egg products, meat, vegetables, or fruits can also carry the disease. Most vulnerable are children, pregnant women, aged individuals, and people with weakened immune systems.

Symptoms: Blood in stool, Chills, Headache, Diarrhea, Vomiting, Abdominal cramps

Prevention: Avoid touching birds or reptiles.

Treatment: Treatment includes ample rest, drinking fluids and electrolytes. More severe infections can be treated with hospitalization and antibiotics.

7. Ascariasis

Infective Agent: Roundworms

Mostly transmitted through poor hygiene. It is Usually found in human faeces and is transmitted from hand to mouth along with contaminated food or water.

Symptoms: Victim is generally asymptomatic, Presence of live worm in stool, Wheezing, Cough, Fever, Severe abdominal pain, Vomiting, Restlessness, Disturbed sleep.

Prevention: Along with general preventions things that to be taken care are; Getting the pets dewormed quickly, Avoid contact with pet's stool, Teaching children not to eat dirt or soil.

Treatment: The most common treatment for roundworms is a medication called albendazole. Doctor may also prescribe an iron supplement. A soothing cream to stop the itching pain. Sometimes, the treatments need to be repeated after several weeks to make sure the roundworms eggs are completely eradicated.

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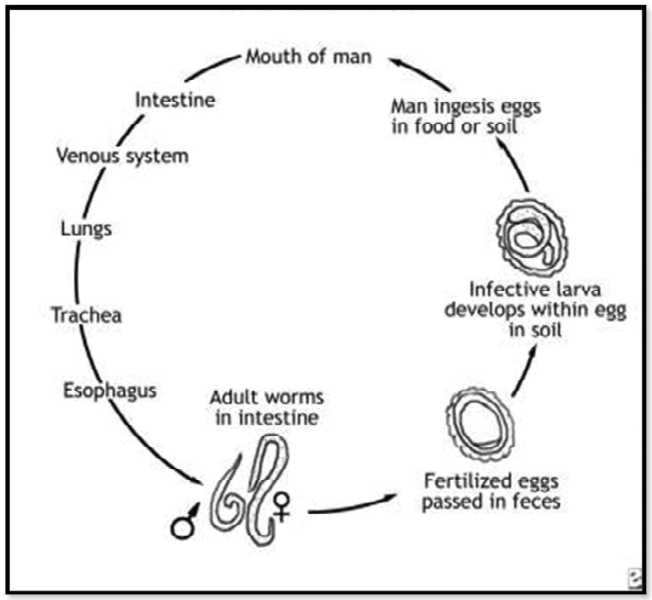

Fig. 4.19 *Life Cycle of* Ascaris lumbricoides

Figure 4.19 is depicting life cycle of *Ascaris lumbricoides*

8. **Amoebiasis**: This is also known as amoebic dysentry

Causative Agent: *Entamoeba histolytica*

Mode of Transmission: Consuming food and water contaminated with cyst.

Life Cycle: No intermediate host is present.

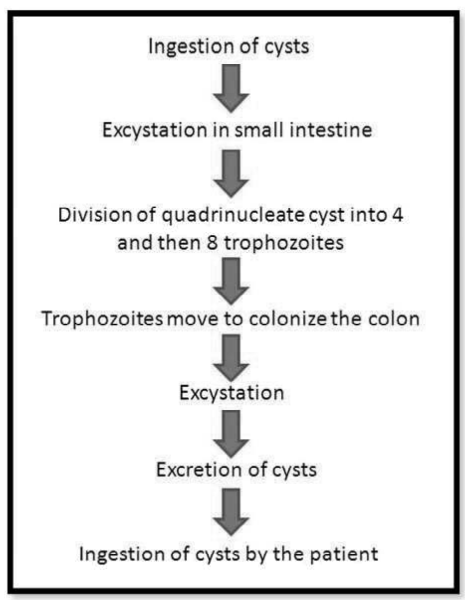

Fig. 4.20 *Life Cycle of* Entamoeba histolytica

Figure 4.20 is depicting life cycle of *Entamoeba histolytica*.

Trophozoite stage releases histolytic enzymes while penetrating the colon leading to formation of ulcers. The rupturing of ulcers releases blood and mucus in the intestine which comes out along with stool of the patient. Trophozoite can also reach lung, liver or brain where they can form abscess.

Treatment: First course of Metronidazole which finish off the trophozoites followed by paromycin, furoate, idoquinol or diloxanide to kill the cysts.

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9. Balantidial Dysentery

Causative Agent: *Balantidium coli*

Mode of Transmission: By consuming food or water contaminated with cyst of parasite.

Symptoms: Diarrhoea and ulceration of the large intestine.

Treatment: Tetracycline, carbasome, metronidazole, and diiodohydroxyquine.

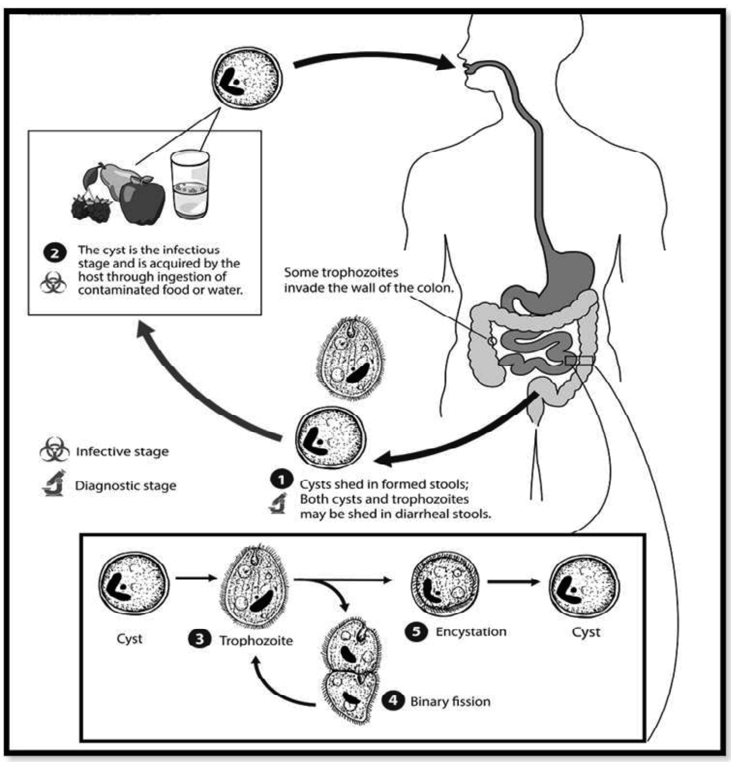

***Fig. 4.21** Life Cycle of* Balantidium coli

Figure 4.21 is depicting life cycle of *Balantidium coli*. Cysts are the stage which are responsible for transmission of balantidiasis.

1) Host acquires the infection via contaminated food or water.
2) Excystation occurs in the small intestine and the trophozoites colonize the large intestine.
3) Trophozoites replicate by binary fission inside the lumen of large intestine or appendix.
4) Trophozoites undergo encystation to produce infective cysts.
5) Trophozoites either invade the colon wall causing ulcerative pathology or return to the lumen and disintegrate. Mature cysts are passed with faeces.

10. Ancylostomiasis

Causative Agent: *Ancylostoma duodenale, Nector americanus* (commonly known as hookworm).

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Life Cycle:

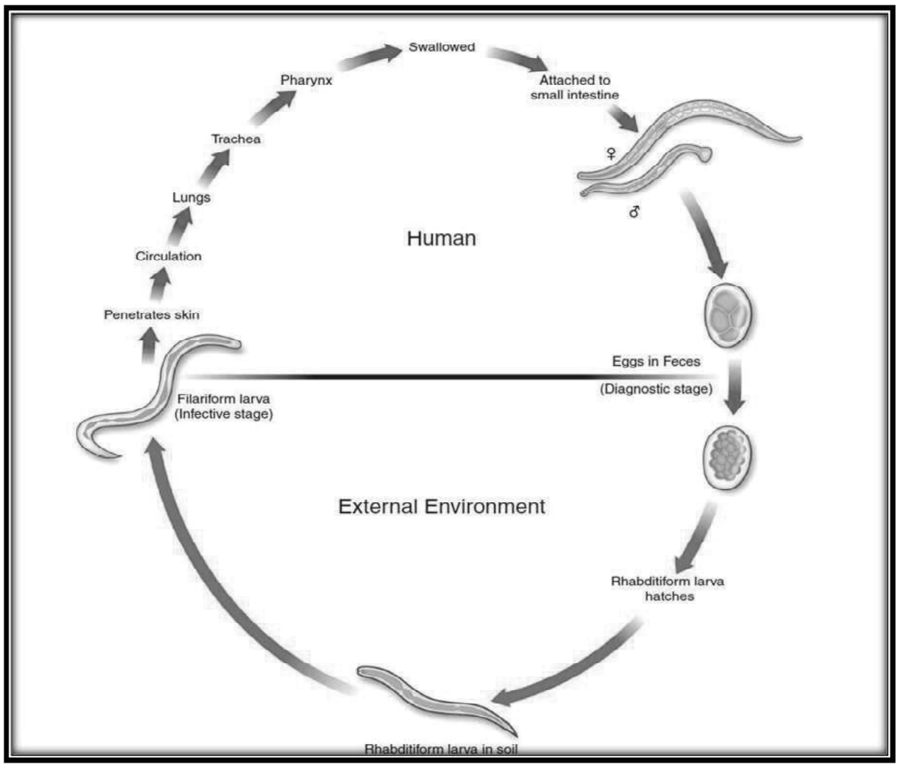

Fig. 4.22 *Life Cycle of* Ancylostoma duodenale

Figure 4.22 illustrates the life cycle of *Ancylostoma duodenale.*

Symptoms: Gastro-intestinal problems, anaemia, dizziness, nausea, vomiting and in severe case men become impotent and females infertile

Treatment: Medications like tetrachloroethane and carbon tetrachloride.

11) **Trichuriasis**

Causative Agent: *Trichuris trichiura*, commonly known as whip-worms. They mainly colonize the vermiform appendix or large intestine.

Mode of Transmission: consumption of food and water contaminated with eggs.

Life cycle:

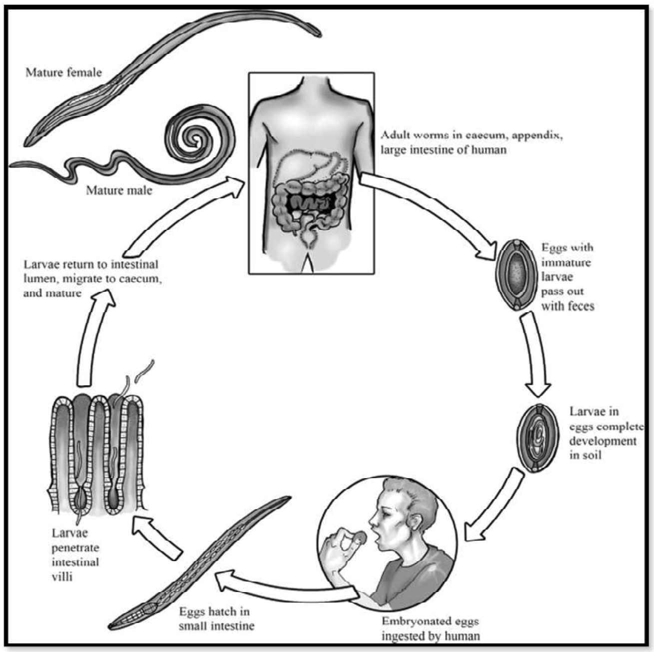

Fig. 4.23 *Life Cycle of* T. Trichiura

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Figure 4.23 is depicting life cycle of *T. trichiura*

Symptoms: Vomiting, nausea, constipation, headache, fever and pain resembling appendicitis.

Treatment: Medication include drug like osarsol, dithiazanine

12) **Strongyloidosis**

Causative Agent: *Strongyloides stercoralis*, commonly called as thread worm.

Life Cycle:

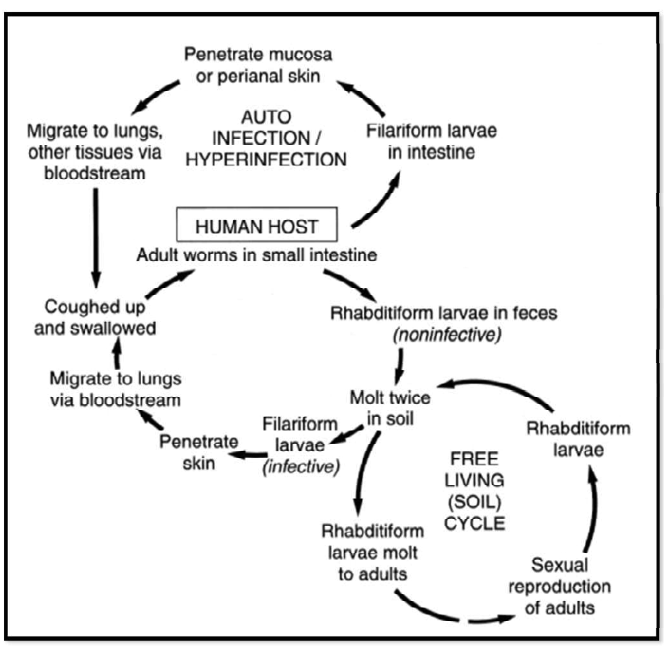

Fig. 4.24 *Life Cycle of* Strongyloides stercoralis

Figure 4.24 is depicting life cycle of *Strongyloides stercoralis.*

Symptoms: Bloody diarrhoea, nausea, vomiting, fever, cough, etc.

Treatment: Drugs like gentian violet and dithiazamine works best.

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Water Borne Diseases and Public Health

Water borne diseases are regarded to be important of public health due to the following reasons:

- Water borne diseases have the potential for causing large outbreaks.
- High disease burden owing to large number of hospital cases and deaths, especially in young individuals.
- In many Indian states as well as districts, water borne diseases is chief cause of pediatric indoor admissions as well as outpatient visits to the hospitals.
- No specific treatment is available for some viral diseases such as hepatitis.
- Increasing anti-microbial drug resistance is being recorded for some water borne bacterial diseases.

Water borne diseases have the potential for causing panic in the community as well as negative media coverage.

Check Your Progress

12. Define point source pollution.
13. What is an aquifer?
14. What do you understand by the term ground water pollution?
15. What are the five major categories of wetlands?
16. How wetlands helps in floodwater storage and control.
17. When 'World Wetlands Day' was first celebrated?
18. What are water borne diseases?

4.8 ANSWERS TO ‘CHECK YOUR PROGRESS’

1. Hydrological cycle is also referred to as water cycle. It refers to as the continuous process by which water is circulated throughout the earth and its atmosphere.
2. Tintometer is a kind of visual colour measuring instrument. It measures colour scale unit which is an international acknowledged specific colour method as a standard to measure the colour of liquid, solid, gelatin, and powder samples.
3. Water is called the “universal solvent”, as it is capable of dissolving more substances than any other liquid.
4. The material that increases the turbidity of water includes slit, tiny organic matter, inorganic material, clay, plankton, dissolved matter as well as other microscopic organism.
5. The pH value of pure water is 7. It is considered to be acidic when value is less than 7, however, it is said to be alkaline if pH value is greater than 7.

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6. Calcium, Magnesium, Sodium, and Potassium are the major cations present in water and Bicarbonates, Carbonate, Chloride, Sulphate, Nitrate, and Phosphate are the major anions present in water.
7. Parameters which needs to be taken into consideration before discharging water are: Total solids, biological oxygen demand (BOD), chemical oxygen demand (COD), nitrates and phosphates, oil and grease, toxic metals, etc.
8. Pre-treatment involves removing large solid items like sanitary items, diapers, wipes, broken bottles, or debris, etc. from the raw sewage. This is an essential step as allowing such items further in the process can damage the equipment used for treating waste water.
9. Neutralization method is used for treating industrial waste water. In this method, base or acid is mixed with water till it reaches the pH value of water. Generally, lime is used as a base to neutralize acidic water.
10. Wetlands prevents climate change in two ways: Firstly, they acts as carbon sinks, i.e. they store greenhouse gases, with approximations showing that wetlands especially peat and forested wetlands store as much as 40% of the global terrestrial carbon. Secondly, as mentioned above their ability to capture and purify water and their storm and wind buffering capacity can protect us from the deleterious effects of climate change like changing rainfall patterns, rising sea level, higher storm frequencies as well as in general extreme weather phenomena.
11. The clearing, transformation or drainage for agricultural development is the chief cause of inland wetland loss worldwide.
12. Point source pollution refers to contaminants or harmful/toxic compounds that enter into aquatic bodies via a fixed source such as a pipe or ditch. For instance; discharges pipes from a sewage treatment plant of factories or several other organizations.
13. When a unit of rock or any unconsolidated deposit can yield a usable quantity of water, it is referred to as aquifer. An aquifer is an underground layer of water-bearing permeable rock, rock fractures or unconsolidated materials (gravel, sand, or silt).
14. Groundwater pollution refers to the change in the physical, chemical, and biological properties of groundwater due to contamination by chemicals, hazardous materials, chemicals, and other foreign particles. Groundwater can be polluted either via natural sources or man-made sources.
15. Wetlands could be classify into five major categories namely:
    - Marine wetlands (coastal wetlands including coastal lagoons, rocky shores, and coral reefs)
    - Estuarine wetlands (including deltas, tidal marshes, and mangrove swamps)
    - Lacustrine wetlands (wetlands associated with lakes)
    - Riverine wetlands (wetlands related to rivers and streams)
    - Palustrine wetlands (meaning “marshy” – marshes, swamps and bogs)
16. Wetlands helps in floodwater storage as well as control. When water levels get very high due to excessive rainfall, the vegetation slows down the flow

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of water and stores part of it in the soil or in the surface which then reduces flooding as well as erosion downstream.

17. 'World Wetlands Day' was first celebrated in 1997 and from there onwards it was celebrated each year on 2nd February to mark the anniversary of the Ramsar Convention. The main aim of the 'World Wetlands Day' is to promote its mission of protecting the wetlands.
18. Water borne diseases are referred to as those diseases that spreads via drinking or using contaminated water. Water generally gets contaminated under poor hygienic or in-sanitary conditions.

4.9 SUMMARY

- Life without water is impossible on earth owing to its several uses in day-to-day life.
- Every living entity on earth-be it plants or animals needs water for carrying out its metabolic process
- Water is a colourless, tasteless and odourless liquid.
- The taste or odour of a particular water sample is due to the presence of inorganic or organic substance present in it.
- The colour of the water is due to the presence of suspended particles as well as organic matter in it.
- Tintometer is an instrument used to measure the colour of water.
- Water is called the 'universal solvent' as it is capable of dissolving more substances than any other liquid.
- Water molecules have a polar arrangement of oxygen and hydrogen atoms—one side (hydrogen) has a positive electrical charge and the other side (oxygen) had a negative charge.
- Hydrological cycle refers to as the continuous process by which water is circulated throughout the Earth and its atmosphere.
- 97% of the earth's water is in the oceans or sea as is referred to as saline water and only 3% of the water present on the continents is freshwater.
- Turbidity refers to the measure of relative clarity of a liquid. It is an optical characteristic of water and is a measurement of the amount of light that is scattered by material present in the water when a light is passed through the water sample.
- The material that increases the turbidity of water includes slit, tiny organic matter, inorganic material, clay, plankton, dissolved matter as well as other microscopic organism.
- Higher turbidity makes the water cloudy or opaque and is an indicator of potential pollution present in the water bodies.
- The turbidity of the water is measured by using an instrument known as turbidity rod or by a turbidity meter with optical observations.
- Cohesion refers to the attractive force present between similar molecules in the same phase.

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- Adhesion refers to the attractive force present between molecules in two different phases like between liquid and solid.
- Surface tension refers to the property of the surface of a liquid that allows it to resist an external force, due to the cohesive nature of its molecules.
- The surface tension of water causes water molecules at the surface of the liquid (in contact with air) to hold closely together, forming an invisible film.
- The surface tension of water is 72 dynes/cm at 25°C.
- Specific heat refers to the amount of heat required to raise the temperature of a 1-gram sample of a substance by one degree Celsius.
- Latent heat of fusion is the heat required by a specific quantity of the substance to change its state from a solid to a liquid, at constant pressure.
- The heat of vaporization is referred to as the amount of heat needed to turn 1 g of a liquid into a vapour, without a rise in the temperature of the liquid.
- Total Dissolved Solids (TDS) present in water can be determined by evaporating a sample of water and then weighing the dry residue left on the filter paper.
- TDS is measured in ppm or mg/l. The amount of TDS in water determines its suitability for our consumption. Table below depicts how the quality of water changes with the TDS values.
- The pH value of pure water is 7, i.e., pure water is neutral. The pH value is defined as the effective concentration of H^+ ions present in water.
- If the hardness of water can be simply removed by boiling it or by adding lime water to it then it is known as temporary hardness of water.
- The bicarbonates and carbonates of calcium and magnesium are usually responsible for causing temporary hardness in water. It is also known as carbonate hardness.
- If the hardness of water cannot be removed by simply boiling it then such water is known as permanent hardness of water.
- The sulphates, chlorides and nitrates of calcium or magnesium are responsible for causing permanent hardness in water. Permanent hardness is also known as non-carbonate hardness.
- Dissolved oxygen (DO) is the amount of oxygen that is present in water. Water bodies receive oxygen from the atmosphere and from aquatic plants.
- Biological Oxygen Demand (BOD) or Biochemical Oxygen Demand (BOD) is referred as the amount of oxygen needed or demanded by aerobic microorganisms to break down the organic matter present in a certain sample of water at a specific temperature over a given period of time.
- The Chemical Oxygen Demand (COD) represents the amount of oxygen necessary for the aerobic biological oxidation (breakdown) of the organic substances in a given water body or sample to carbon dioxide (CO_2) and water (H_2O) if the organics are actually biodegradable.
- Phytoplankton are small microscopic, unicellular and photosynthetic organisms which freely float in water bodies.

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- Eutrophication refers to the process in which a water body becomes overly enriched with nutrients, leading to excessive growth of growth of algae and plankton.
- Zooplanktons are microscopic, unicellular or multicellular forms with size ranging from a few microns to a millimetre or even more.
- Sewage treatment, or domestic wastewater treatment refers to the process of removing physical, chemical and biological contaminants/pollutants from them.
- The main objective of the waste water treatment is to produce an environmentally-safe fluid waste stream (or treated effluent) or reuse the water either by humans/animals or for any other purpose like as farm fertilizer.
- Conventional sewage treatment involve three stages namely primary, secondary and tertiary treatment.
- Waste water treatment helps in reducing the water pollution at surface level and also, it prevents the outbreak of water borne diseases.
- Water obtained from waste water treatment plants can be used for multiple purposes like human consumption/agricultural purposes/industrial use etc.
- Inland waters include lakes, rivers, ponds, streams, groundwater, springs, cave waters, floodplains, as well as bogs, marshes and swamps, which are traditionally grouped as inland wetlands.
- Inland waters are aquatic-influenced environments located within land boundaries.
- Inland waters include lakes, rivers, ponds, streams, groundwater, springs, cave waters, floodplains, as well as bogs, marshes and swamps, which are traditionally grouped as inland wetlands.
- Inland waters cover less than 2% of the total earth's surface, i.e., approximately 2.5 x 106 km^2.
- Those aquatic system which contains standing or stagnant water are referred to as Lentic aquatic systems.
- Lotic aquatic systems are those systems which contain flowing waters.
- Groundwater refers to the water present beneath Earth's surface in rock and soil pore spaces and in the fractures of rock formations.
- Groundwater pollution refers to the change in the physical, chemical and biological properties of groundwater due to contamination by chemicals, hazardous materials, chemicals and other foreign particles.
- Surface water pollution refers to the change in the physical, chemical and biological properties of surface water (lakes, rivers, streams, and oceans) due to contamination by chemicals, hazardous materials and other foreign particles.
- Point source pollution refers to contaminants or harmful/toxic compounds that enter into surface water via a fixed source such as a pipe or ditch.
- Non-point source (NPS) pollution resulting from diffuse or vastly scattered sources in contrast to point source pollution.

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- Water pollution affects the physical, chemical and biological characteristics of water making it highly unfit for human consumption and also leads to severe diseases.
- Turbidity refers to an optical characteristic of water and is a measurement of the amount of light that is scattered by material present in the water when a light is passed through the water sample.
- Higher turbidity makes the water cloudy or opaque. In fact, turbidity of the water is an indicator of potential pollution present in the water bodies.
- Bio-accumulation refers to the entry of a pollutant or toxic/hazardous substance in the food chain.
- Bio-magnification is defined as the increase in concentration of a toxic substance at each successive trophic level after entering into food chain.
- Oil spills leads to the formation of a thick layer of oil on the surface of water and stops marine plants from receiving enough light for carrying out the process of photosynthesis as well as it can disturb the free flow of oxygen in the water.
- Under the Ramsar Convention, a broad classification of wetlands has been defined to help in rapid identification of wetland at each Ramsar site.
- Ramsar classification simplifies the portrayal of wetlands by dividing it based on geographic location and human parameters, however the fact that overlaps happen since the categories are not always mutually exclusive.
- Water borne diseases are referred to as those diseases that spreads via drinking or using contaminated water. Water generally gets contaminated under poor hygienic or in-sanitary conditions.
- The water can be contaminated with either human or animal faeces and the diseases transmitted by drinking such water are known as faeco-orally transmitted diseases.
- Water borne diseases can also be transmitted through eating food prepared using contaminated water or using utensils which have been washed with the contaminated water.

4.10 KEY TERMS

- **Water:** Water is an inorganic, transparent, tasteless, odourless, and nearly colourless chemical substance, which is the main constituent of Earth's hydrosphere and the fluids of all known living organisms.
- **Ecosystem:** An ecosystem (or ecological system) consists of all the organisms and the physical environment with which they interact.
- **Hydrological cycle:** The water cycle, also known as the hydrologic cycle or the hydrological cycle, is a biogeochemical cycle that describes the continuous movement of water on, above and below the surface of the Earth.
- **Solvent:** A solvent is a substance that dissolves a solute, resulting in a solution. A solvent is usually a liquid but can also be a solid, a gas, or a supercritical fluid.

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- **Turbidity:** Turbidity is the cloudiness or haziness of a fluid caused by large numbers of individual particles that are generally invisible to the naked eye, similar to the smoke in air.
- **Cohesion:** Cohesion refers to the attractive force present between similar molecules in the same phase. Cohesion helps hold a column of water together against the force of gravity.
- **Adhesion:** Adhesion refers to the attractive force present between molecules in two different phases like between liquid and solid.
- **Surface tension:** Surface tension refers to the property of the surface of a liquid that allows it to resist an external force, due to the cohesive nature of its molecules.
- **Specific heat:** Specific heat refers to the amount of heat required to raise the temperature of a 1gram sample of a substance by one degree Celsius. The specific heat of water is 4.184 joules per gram per degree Celsius.
- **Latent heat of fusion:** It is the heat required by a specific quantity of the substance to change its state from a solid to a liquid, at constant pressure.
- **pH Value:** pH is a scale used to specify the acidity or basicity of an aqueous solution. Acidic solutions (solutions with higher concentrations of H ions) are measured to have lower pH values than basic or alkaline solutions. The ideal pH value of water is 7 (neutral).
- **Temporary hardness:** If the hardness of water can be simply removed by boiling it or by adding lime water to it then it is known as temporary hard water.
- **Permanent hardness:** If the hardness of water cannot be removed by simply boiling it then such water is known as permanent hard water.
- **Waste water treatment:** Wastewater treatment is a process used to remove contaminants from wastewater and convert it into an effluent that can be returned to the water cycle.
- **Disinfection:** A disinfectant is a chemical substance or compound used to inactivate or destroy microorganisms on inert surfaces. It is less effective than sterilization, which is an extreme physical or chemical process that kills all types of life.
- **Sludge:** Sludge is a semi-solid slurry that can be produced from a range of industrial processes, from water treatment, wastewater treatment or on-site sanitation systems.
- **Sewage treatment:** It is a type of wastewater treatment which aims to remove contaminants from sewage to produce an effluent that is suitable for discharge to the surrounding environment or an intended reuse application, thereby preventing water pollution from raw sewage discharges.
- **Soil erosion:** Soil erosion is the displacement of the upper layer of soil; it is a form of soil degradation. This natural process is caused by the dynamic activity of erosive agents, that is, water, ice (glaciers), snow, air (wind), plants, animals, and humans.

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- **Oil spills:** An oil spill is the release of a liquid petroleum hydrocarbon into the environment, especially the marine ecosystem, due to human activity, and is a form of pollution.
- **Water pollution:** Water pollution (or aquatic pollution) is the contamination of water bodies, usually as a result of human activities, in such a manner that negatively affects its legitimate uses.
- **Eutrophication:** Eutrophication refers to the process in which a water body becomes overly enriched with nutrients, leading to excessive growth of algae and planktons.
- **Bioaccumulation:** The phenomenon of bioaccumulation refers to the entry of a pollutant or toxic/hazardous substance in the food chain.
- **Biomagnification:** It is defined as the increase in concentration of a toxic substance at each successive trophic level after entering into food chain.
- **Biological Oxygen Demand (BOD):** It is referred as the amount of oxygen needed or demanded by aerobic microorganisms to break down the organic matter present in a certain sample of water at a specific temperature over a given period of time.
- **Chemical Oxygen Demand:** It represents the amount of oxygen necessary for the aerobic biological oxidation (breakdown) of the organic substances in a given water body or sample to carbon dioxide (CO2) and water (H2O) if the organics are actually biodegradable.
- **Water borne disease:** Waterborne diseases are essentially infectious diseases in which the pathogen is spread by water. These diseases can be spread while bathing, washing, drinking water, or by eating food exposed to contaminated water.

4.11 SELF ASSESSMENT QUESTIONS AND EXERCISES

Short-Answer Question

1. How the earth's water enters the atmosphere?
2. Why pure water is less conductive than any other water?
3. Which property of water molecules allows it to become attracted to many other different types of molecules?
4. What is the difference between cohesion and adhesion?
5. Why does water has a very high specific heat?
6. Define hardness of water. What are its types?
7. What is the main objective of the waste water treatment?
8. Define Sludge Treatment.
9. What are three common methods of biological treatment?
10. What are advantages of Waste Water Treatment?
11. How wetlands serves as a natural sewage system?
12. How the aquatic ecosystems can be protected or restored?

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13. List down the major water pollutants.
14. Write few guidelines for effectively managing or reducing the groundwater pollution.
15. How the turbidity of the water indicate of potential pollution present in the water bodies?
16. State how Oils Spills affects the floral and faunal Diversity?
17. Write a few characteristics of wetlands.
18. How the wetlands prevents climate change?
19. How the wetlands serves as a natural sewage system?
20. In which areas water-borne diseases are more prone to widespread?
21. Why water borne diseases are regarded to be important to maintain public health?
22. Which wetlands are not regulated in India under wetlands rules?

Long-Answer Question

1. Give a detail account of physical, chemical and biological properties of water.
2. Describe waste water treatment process in detail.
3. Elaborate on the different methods of waste water treatment.
4. Briefly describe the importance of inland water and wetlands.
5. Describe the major threats to inland waters and wetlands in detail.
6. Write a detail note on causes of pollution of aquatic resources and their management.
7. Explain the process of eutrophication and its effects on a water body.
8. Discuses some measures which could be adopted for reducing water pollution.
9. Analyse how water pollution affects the physical, chemical and biological characteristics of water.
10. Write a short note on 'State Wetland Authority' (SWA).
11. What are water borne human diseases? Explain some water borne disease their symptoms and preventions.

4.12 FURTHER READING

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