Introduction to Aquatic and Wetland Ecosystems (Biol 3091)

1.1. Definitions and Global Proportions

Defining one of the two major ecosystem categories: Aquatic ecosystem. These are ecosystems that occupy the largest part of the biosphere and are covered with water. There are two major categories of aquatic biomes

Fresh water ecosystems: with salt concentration of < 3 gm/l or 3 parts per thousand (ppt.),

These inland water bodies are closely linked to soils and biotic components of terrestrial biomes through which they pass and are influenced by patterns and speed of water flow and climate of area in which its located.

There are two categories of freshwater ecosystems

Standing (lentic) bodies of water which include lakes, ponds and inland wetlands; and **moving** (lotic): bodies of water which include rivers and streams

A. Lakes are large, natural bodies of standing water which could be fresh or saline.

Lakes are formed when precipitation, runoff, groundwater seepage fills depressions in earth's surface. These depressions can be formed by

- glaciation (Great Lakes, NA)
- tectonic or crustal displacement (Lake Victoria, East Africa; Lake Baikal, Russia; Rift valley lakes)
- volcanic activity (Bishoftu crater lakes)

❖ Lakes could have different shapes (morphometry) depending on how they were formed and how geological processes have modified them. Large lakes may have many characteristics similar to oceans, such as a large pelagial (open water) region, deep depth, an extensive bottom area (benthic region), etc.

- This is a water ecosystem that provides many vital environmental functions both to human being and other organisms. For example:
  - They are important in nutrient recycling, flood attenuation and habitat provision to wildlife (biodiversity).
  - The largest proportion of rainfall comes from evaporation of water bodies.
  - They are also used for human recreation, and are very important to the tourism industry, especially in coastal regions.
- Aquatic ecosystems are composed of biotic communities (also called biota) and a biotic environmental factor, which form a self-regulating and self-sustaining unit. The biotic components of aquatic ecosystems are either autotrophic or heterotrophic.
- Abiotic environmental factors of aquatic ecosystems include the amount of dissolved oxygen (DO), temperature, amount of light, salinity, pH, nutrients such as nitrogen (in the form of mainly nitrates) and phosphorus (in the form of phosphates).
- The amount of dissolved oxygen in a water body is frequently the key substance in determining the extent and kinds of organic life in the water body. Fish need dissolved oxygen to survive. Conversely, oxygen is fatal to many kinds of anaerobic bacteria. The salinity of the water body is also a determining factor in the kinds of species found in the water body.
- Organisms in marine ecosystems tolerate salinity, while many freshwater organisms are intolerant of salt. Freshwater used for irrigation purposes often absorb levelsof salt that are harmful to freshwater organisms.

There are three major types of aquatic ecosystems:

1) Inland (mainly freshwater) Aquatic Ecosystems
2) Marine Ecosystems
3) Estuarine Ecosystems

- The inland aquatic ecosystems include; lakes, rivers and streams that have negligible salinity (salt content) of a little greater than or equal to 10 grams of salt per 1 liter of water. The waters of inland aquatic ecosystems are said to be largely freshwater with an exception of a few salty lakes.
- The marine ecosystems include seas and oceans and are characterized by high salinity reaching 370 gram of salt per liter of water. All marine waters are salty. The estuarine ecosystems are areas formed at the junction of the freshwater and marine waters.

❖ The largest proportion, about 75 %, of the Earth's surface is covered by water. Marine ecosystems cover approximately 71 % of the Earth's surface and constitute about 97 % of the planet's water. The inland aquatic ecosystems, in contrast, account only for smaller proportion covering about 0.8 % of the Earth's surface and constituting 3 % of its total water. About 68.7 % of this is either frozen in glaciers and ice and 30.1 % is buried in aquifers as groundwater. The remainder is found as surface waters (in lakes, ponds, rivers, and streams) and as moisture. Lakes constitute the largest proportion (87%) of the surface waters.

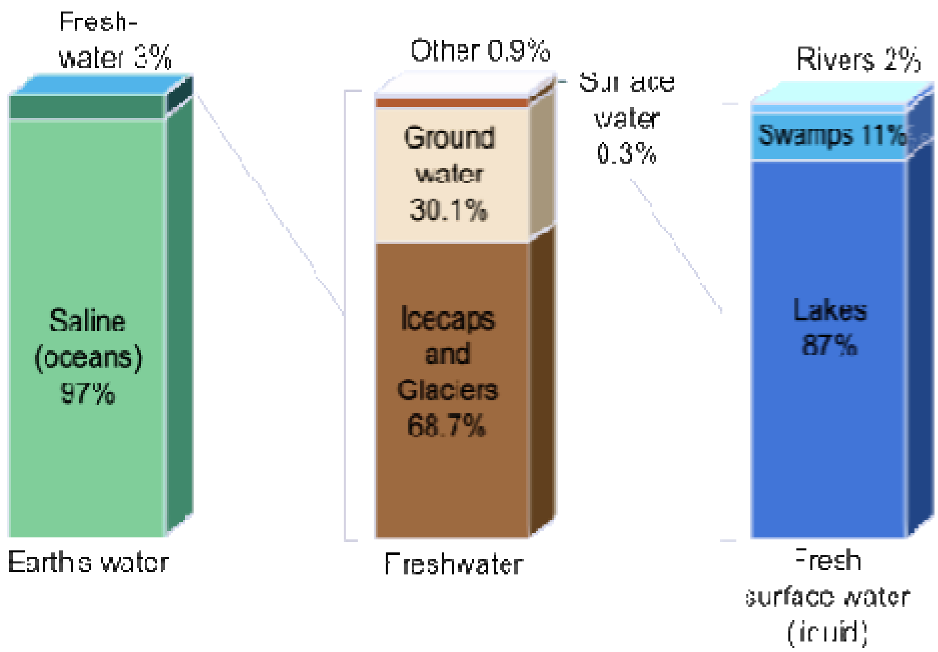


Fig.1.1. Distribution of Earth's Water

1.2. The Inland Aquatic Ecosystems

These refer to the bodies of water that are totally land locked and include freshwater ecosystems typically the lakes and rivers characterized by having low salinity of about 0.1 % or 1 % (i.e.1 gram of salt per 1kg or 1 L of water).The inland water bodies are closely linked to the terrestrial biomes that surround them or through which they flow. Overall characteristics of freshwater ecosystems are influenced by the pattern and speed of water flow, and the local climate.

The freshwater ecosystems generate nearly 3 % of net primary production and contain 41% of the world's known fish species. Three basic types of inland aquatic ecosystems can be recognized. These are lentic, lotic and wet land ecosystems.

- Lentic freshwater ecosystems are standing freshwater ecosystems such as lakes and ponds.

- Lotic freshwater ecosystems are the rapidly moving fresh water ecosystems such as rivers and streams.

1.2.1. Lentic Freshwater Ecosystems

Lakes and deeper ponds exhibit temperature stratification known as thermal stratification during the summer (warmer) and winter seasons in temperate zones.

However, the effect of thermal stratification is more pronounced during summer season when still air condition is more prevalent. Sunlight heats the upper layers of water as far as it penetrates and the deeper water remains cold. Consequently, the warmer upper water (known as epilimnion), becomes separated from the lower colder water (known as hypolimion). A narrow zone of water that separates between the warmer and colder waters undergoes a rapid or exponential temperature change and it is known as thermocline (See Fig. 1.2. below)

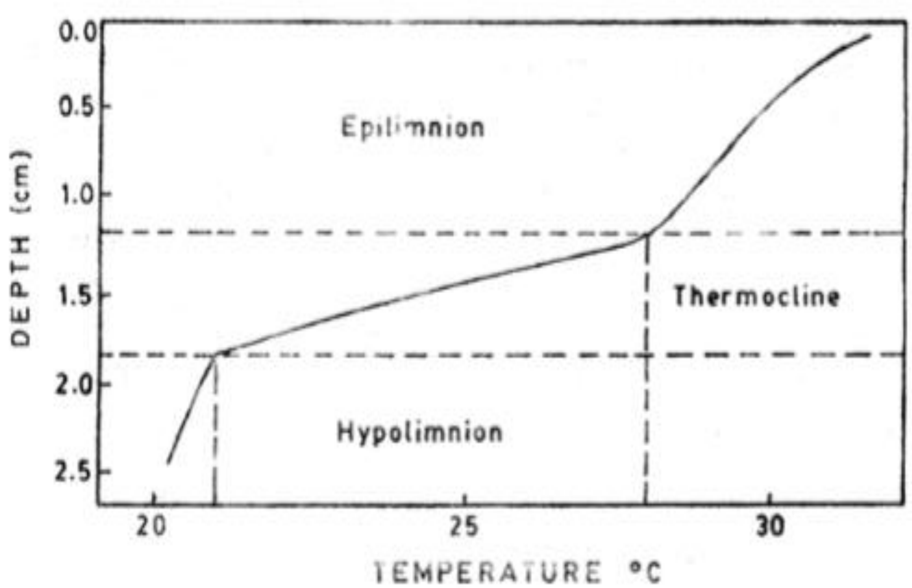


Fig 1.2. An Illustration of Thermal Stratification

Lakes are often classified as:

- **Oligotrophic lakes**: are often deep, nutrient-poor lakes in which the Phytoplankton is not very productive. In oligotrophic lakes the water is usually clear and the profundal (bottom) zone has high oxygen concentration since little detritus is produced in the limnetic (upper) zone to be decomposed.

- **Mesotrophic lakes:** lakes having moderate productivity level
- **Eutrophic lakes**: are shallow, nutrient-rich lakes with very productive phytoplankton.

The eutrophic waters are usually murky due to large phytoplankton populations and the large amounts of detritus being decomposed may result in oxygen depletion in the profundal zone.

The classification of lakes in to such trophic classes is based on the level of productivity or amount of organic matter produced. Trophic status of a lake thus, reflects the productivity level of a lake. Oligotrophic lakes may develop into eutrophic lakes over time if runoff from surrounding terrestrial habitats brings in mineral nutrients such as nitrates and phosphates. Human activities increase the nutrient content of runoff through:

- Lawn and agricultural fertilizers
- Municipal wastes

These activities enrich lakes with the nitrogen and phosphorus concentrations which in turn increases phytoplankton and plant growth. Algal blooms and increased plant growth results in more detritus and can lead to oxygen depletion due to increased decomposition. Moreover, Lake Ecosystems can be divided into various horizontal and vertical zones such as littoral, limnetic and profundal. Ponds are a specific type of freshwater ecosystems that are largely based on the autotrophic algae which provide the base trophic level for all life in the area. The largest predator in a pond ecosystem is normally fish and in between range smaller insects and microorganisms. It may have a scale of organisms from small bacteria to big creatures like water snakes, beetles, water bugs, frogs, tadpoles, and turtles.

1.2.2. Lotic Freshwater Ecosystems

Lotic ecosystems are water bodies such as rivers and streams that move continuously in one direction. The structure of lotic ecosystems changes from their point of origin (headwaters) to where they empty into a larger body of water (mouth).

At the headwaters, the water:

- Is cold and clear
- Carries little sediment
- Has few mineral nutrients
- The channel is narrow with a rocky substrate
- The water flows turbulently

- Near the mouth, the water:
- Moves slowly and is more turbid due to sediment entering from other streams and erosion
- The nutrient content is also higher
- The channel is usually wider with a silty substrate that has resulted from deposition of silt.

Rivers with rough and shallow bottoms produce turbulent flow known as riffles. In contrast, rivers with smooth and deep bottoms result in a slower, smooth flow called pools.

Nutrient content of the water is higher in streams and rivers flowing through densely vegetated regions due to leaves and other vegetation entering the water adding organic matter and where erosion takes place which increases inorganic nutrient content. Oxygen content of the water is affected by the flow rate;

- Turbulent flow constantly oxygenates the water giving rise to greater biodiversity
- While slow pool water contains relatively little oxygen and poor biodiversity.

Turbidity reflects the amount of material suspended in the water; streams and rivers flowing through areas of high erosion will have more suspended materials than those surrounded by hard substrates. Large amounts of suspended organic matter also increase turbidity.

The biological communities found in rivers and streams also differ from headwaters to mouth; they also differ from those found in ponds and lakes. In upstream areas where water is cool, clear and has high oxygen content, many insects and fish are found.

Due to the relatively high-water current, large plankton communities are not common in rivers and streams. Thus, photosynthesis which supports the food chains are a function of attached algae and rooted plants.

1.3. Marine Ecosystems

Here salt concentration exceeds 35 ppt or gm/l. This biome includes oceans and seas which cover ~ 75% of the earth’s surface and have enormous impact on planet’s climate Marine ecosystems provide most of the planet's rainfall through evaporation. The world's climate and wind patterns are also affected by ocean temperatures. They generate 32 % of the world's net primary production. Marine algae produce a large portion of the Earth's oxygen and consume large amounts of carbon dioxide. Although the actual salinity varies among different marine ecosystems, they are generally characterized by high salinity of 3.7 % or 37 ‰ (i.e. 37 grams of salt per 1 kg or 1 L of water).

Marine ecosystems can be divided into various horizontal and vertical zones such as intertidal (littoral), neritic, oceanic, etc.

The following some examples of abiotic factors important in marine ecology:

- **Temperature** affects biological processes and the ability of most organisms to regulate their body temperature. Temperature affects metabolism: few organisms have active metabolisms at temperatures close to 0º C and temperatures above 45º C denature most essential enzymes. The actual body temperature of ectotherms is affected by heat exchange with the environment; most animals maintain a body temperature only a few degrees above or below ambient temperature. Even endotherms function best within the temperature range to which they are adapted.
- **Salinity**: marine organisms can be euryhaline (i.e. wide range of tolerance) or stenohaline (narrow range of tolerance) according to their salt tolerance.
- **Sunlight:** provides the energy that drives nearly all ecosystems although only photosynthetic organisms use it directly as an energy source. In aquatic environments, water selectivity reflects and absorbs certain wavelengths; therefore, most photosynthesis occurs near the water surface. The physiology, development, and behavior of many animals and plants are often sensitive to photoperiod.
- **Rocks and soil**: The physical structure, pH, and mineral composition of soil limit distribution of plants and hence animals that feed on those plants. The composition of the substrate in a stream or river greatlyinfluences the water chemistry, which in turn influences the plants andanimals. The type of substrate influences what animals can attach orburrow in intertidal zones.
- **Wind** amplifies the effects of temperature by increasing heat loss by evaporation and convection; wind also increase the evaporation rate of animals and transpiration rate of plants, resulting in more rapid water loss. Mechanical pressure of wind can affect plant morphology (for example, inhibiting growth of limbs on windward side of trees).
- **Periodic** disturbances such as fire, hurricanes, typhoons, and volcanic eruptions can devastate biological communities, after which the area is recolonized by organisms or repopulated by survivors. May go through a succession of changes. Those disturbances that are infrequent (volcanic eruptions) do not illicit adaptations. Adaptations do evolve to periodically recurring disturbances such as fires.

1.4 Estuarine Ecosystems

An estuary is the area where a freshwater stream or river merges with the ocean. Salinity within the estuary varies from nearly fresh water to ocean water; varies daily in areas due to rise and fall of tides. Thus, the estuarine waters are often known as brackish. Estuaries are very productive due to nutrients brought in by rivers and have a diverse flora and fauna. Salt marsh grasses, algae, and phytoplankton are the major producers. Many species of annelids, oysters, crabs and fish are also present. Many marine invertebrates and fish breed in estuaries. A large number of water fowl and other semiaquatic vertebrates use estuaries as feeding areas.

1.5 Wetland Ecosystems

Wetland ecosystems are areas where the soil is saturated or inundated for at least part of a time. Wetlands occur where the water table is at or near the surface of the land, or where the land is covered by shallow water. In general wetlands can be defined as areas where water is the primary factor controlling the environment and the associated flora and fauna.

The soils of the wetlands are water logged creating anaerobic conditions, they; thus, contain characteristic fauna and flora specially adapted to waterlogged soil condition. Wetlands are, therefore, considered transition ecosystems between the aquatic and terrestrial ecosystems as they are neither fully terrestrial nor are fully aquatic. Globally the total proportion of wetlands is not exactly known mainly due to their seasonal and spatial variability.

Estimates are that wetlands occupy nearly about 6 % of the world's land area which is three times the area of lakes.

Wetlands are among the world's most productive environments important for maintaining key ecological processes and socio-economic benefits to local communities.

Classification of the wetlands into certain categories also varies according to specified characteristics such as vegetation, hydrology, soils, animal species present, function, value, etc and the purpose of classification. According to Ramsar convention, five major wetland types are generally recognized:

- **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 along rivers and streams
- **Palustrine wetlands**: wetlands such as marshes, swamps and bogs

Review Questions

Answer the following questions properly. Refer to the appropriate sections to confirm your answers

1. What are the values of wetlands both to human being and other organisms?

2. What are abiotic components in an ecosystem? Give examples of abiotic components in aquatic ecosystems

3. What are biotic components in an ecosystem? Give examples of biotic components in aquatic ecosystems

4. What are the three major categories of aquatic ecosystems? How do they differ in terms of salinity?

5. What are wetland ecosystems? How do they differ from the aquatic ecosystems?

6. What proportion of the earth's surface is water? What proportion of the earth is freshwater? Marine water?

7. What are the lentic ecosystems? lotic ecosystems? Give examples for each type of ecosystem.

8. What is thermal stratification?

9. What are epilimnion, hypolimnion and thermocline?

10. What are the different categories of lakes according to their productivity? List them down and define each.

11. What is eutrophication? Which human activities may accelerate the rate of eutrophication?

12. What are riffle rivers? Pool rivers?

13. What are the five major categories of wetlands? List them down and define each

2. Major Freshwater Bodies and Wetlands of Ethiopia

2.1. Catchments/Drainage Basins

Catchment (also known as drainage basin) is an area of land where water drains down into water bodies such as river, lake, wetland, seas and oceans. The terms catchment, catchment area, catchment basin, drainage area, drainage basin, river basin, water basin is often used synonymously.

Drainage system is a system of network of streams, rivers, standing water bodies (e.g. lakes) and wetlands together with the catchment area.

Nile (Abay) and Baro-Akobo drainage basins are two of the Ethiopian drainage basins

Adjacent catchments are separated from one another by watershed (also known as a drainage divide) which is an elevation (e.g. mountains, hills or ridges) that separates one catchment area from another catchment area. The term is, however, sometimes used synonymously with catchment. On one side of a watershed, rivers and streams flow in one direction and on the other side they flow in another direction. Because catchments or drainage basins are coherent entities in a hydrological sense, it has become common to manage water resources on the basis of individual basins i.e. they can be used as management units of water resources.

There are numerous ocean drainage basins throughout the world. Examples include the Atlantic Ocean drainage basin, the Pacific Ocean drainage basin, the Indian Ocean drainage basin, the Southern Oceans drainage basin. The Atlantic Ocean drainage basin is the largest draining about 47% of all land in the world.

In the world the three largest river drainage basins (by area), from largest to smallest, are the Amazon basin, the Congo basin, and the Mississippi basin; and the three rivers that drain the most water, from most to least, are the Amazon, Congo, and Ganges Rivers Endorheic drainage basins are inland or closed basins that do not drain out into an ocean whereas exoreic drainage basins are characterized by external drainage. In endorheic drainage basins evaporation is the primary means of water loss and the water is typically more saline.

Catchment characteristics (also known as catchment factors) such as catchment morphology, catchment size, catchment soil, catchment topography, catchment shape, catchment vegetation type, catchment land use system, etc are important factors that affect various aspects of the water body located in the basin.

Catchment geomorphology (rock or soil type) influences the water quality characteristics, such as the nutrients, total suspended solids (TSS) and conductivity, of the water body (river or lake) located in the basin. For instance, if the soil of the catchment is a lime stone, electrical conductivity of the aquatic ecosystem increases because of the dissolution of carbonate minerals. Please see section 5.2 for better understanding of nutrients, TSS, water conductivity, etc.

Catchment size is also important in determining the characteristics of the water bodies located in the catchment area. Catchment size helps determine the amount of water reaching the river, as the larger the catchment the greater the potential for flooding. Moreover, the bigger the catchment means relatively there will be more contact with soil before water reaches the lake. Catchments are thus important elements to consider in ecology because as water flows over the ground it can pick up nutrients, sediment, and pollutants that can affect the ecological processes along the way as well as in the receiving water source.

Catchment topography and shape determine the speed of run off to the river. Run off from mountainous areas reach the river faster than from flat or gently sloping areas and a long thin catchment will take longer to drain than a circular catchment.

The catchment soil type determines the amount of water that reaches the river. Sandy soils are very free draining and rainfall on sandy soil is likely to be absorbed by the ground. However, soils containing clay can be almost impermeable and therefore rainfall on clay soils will run off and contribute to flood volumes.

Catchment vegetation cover is important in reducing surface run off into the water body from the catchment area and thus contributes to good water quality of the water body.

Type of catchment land use can affect the receiving water body in many ways. They contribute to the volume of water reaching the river. More over human practices such as farming, cattle grazing, and industries of various types all can contribute to some sort of pollutants that can reach the water body.

2.2. Drainage Basins of Ethiopia

2.2.1. The Ethiopian Drainage Systems

Ethiopia, often called the water tower of northeast Africa, is endowed with some 7000 km length of flowing water and some 7000 km^2 of standing water. The drainage patterns are the result of the topographic features formed by the recent geologic activity of the Cenozoic Era during the Tertiary Period. Ethiopia, with its various geologic formations and climatic conditions, is endowed with considerable freshwater resources and wetlands.

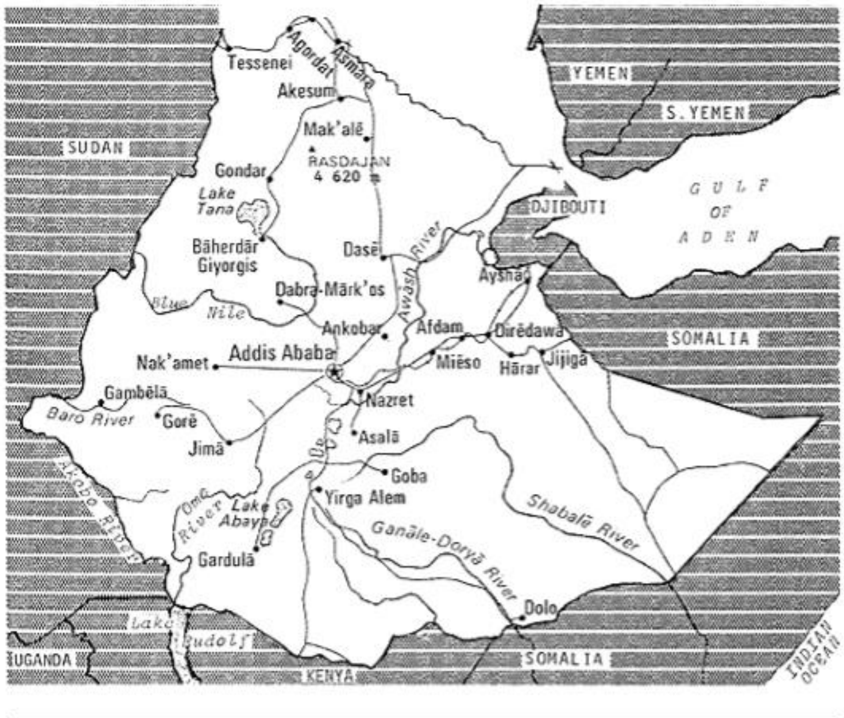


Fig. 2.2. The Major Ethiopian Drainage Systems

The drainage systems of Ethiopia can be broadly divided into three topographic regions which in turn are further subdivided in to drainage basins. These are: the western drainage system, the south eastern drainage system and the Rift Valley drainage system.

- **The Western drainage system**: includes the Tekeze drainage basin, Abay (Blue Nile) drainage basin, Baro-Akobo drainage basin and Gibe-Omo drainage basin. The major lakes, such as Tana Lake, are located within this drainage system. This is the largest drainage system that drains nearly40 % of the total area and 60 % of the annual water flow. This is an exorheic system in which the rivers in the system ultimately drain into the Mediterranean Ocean.
- **The South-eastern drainage system**: includes Wabishebele and Ghenale drainage basins. This is also an exorheic system in which the rivers in this system ultimately drain into the Indian Ocean.
- **The Rift valley drainage system**: includes Awash drainage basin and major lakes such as Ziway, Shala, Abijata, Awassa, Abaya and Chamo are located in the Rift Valley. This is generally an endorheic or closed system with no external flow.

2.2.2. Lakes

The Ethiopian lakes roughly occupy some 7000 km^2 areas. The formation of most of the natural lakes is associated with tectonic and volcanic activities and thus most are crater lakes. The high land lakes include Lake Tana, Lake Hayq (near Dessie), Ashengie, Lake Wonchi (near Ambo), and Bishoftu (Debrezeit) Lake groups (such as Lake Hora, Lake Bishoftu, Lake Kuriftu and Lake Arenguade, etc). The Rift Valley lakes include lakes in:

- The northern rift valley lakes: Awassa, Langano, Abijata, Sahlla and Ziway
- The southern rift valley lakes: Abaya, and Chamo and Chew Bahir

The man-made lakes known as reservoirs include Koka Reservoir, Fincha Reservoir, MelkaWakena Reservoir, Gilgel Gibe Reservoir, Tekeze Reservoir, etc.

Table 2.1. Some of the Major Ethiopian Lakes

Lake	Area (Km2)	Max. Depth (m)
Tana	3600	9
Abaya	1150	13
Chamo	551	10
Ziway	434	4 (shallowest)
Shala	409	266 (deepest)
Abijata	205	14
Koka	205	9
Awassa	129	46

Though fishery activities are not well developed in Ethiopia, some practices are seen in most of the lakes mentioned above. However, most of the fishery activities are common in Rift valley lakes and Lake Tana.

2.2.3. Rivers

The Ethiopian rivers are more than 7000 km long. The major rivers located among the various drainage basins are summarized in Table 2.2. Ethiopian rivers are characterized by:

- Extreme seasonal fluctuation due to the marked seasonality of the rainfall:
    - They carry only small amount of water and some even dry up along part of their courses during dry season.

- High volume and run off during wet seasons

- Steep flow and profiles:
  - ✓ Flowing from highlands of over 2,000-3,000 meters to a low land of an elevation less than 500 meters.
- The rivers have high erosive power due to their steep flow

Table 2.2. The Major Rivers of Ethiopia

River	Length (km)			Major tributaries
	Total	inside	outside	
Abay (Blue Nile)	1360	800	560	Dabus, Didesa, Fincha, Guder, Muger
Wabishebele	2000	1340	660	Ramis, Erer, Daketa, Fafen
Ghenale	1050	480	570	Dawa, Weyb, Welmel, Mena
Awash	1200	1200	-	Akaki, Kesem, Borena, Mile
Tekeze	1168	608	560	Atbara, Angreb
Omo/Ghibe	760	760	-	Gojeb
Baro	507	227	280	Akobo

Many Ethiopian rivers including Abay are difficult for fisher activities primarily due to:

- The steep gorge of the rivers that extends for a large portion of the basin. The presence of crocodiles in many segments of the rivers.
- Moreover, many of the tributaries dry or their volumes are highly reduced during the dry seasons.

The Ethiopian rivers generally flow into:

- Mediterranean Ocean: Which drainage system belongs here?
- Indian Ocean: Which drainage system belongs here?
- Close (inland) flow.i.e. with no external flow: Which drainage system belongs here?

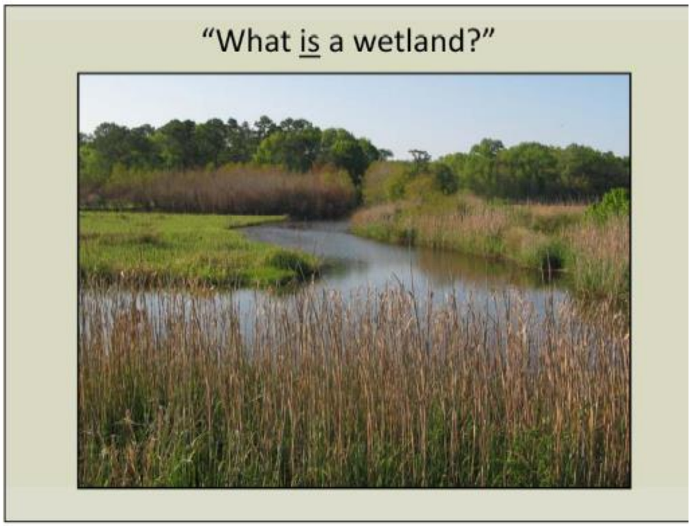
The general flow pattern of Ethiopian rivers is determined by the topography of the country:

- Western and South eastern highlands have an outward slopping topography resulting in the out-ward flow of the rivers. Consequently, most major rivers of Ethiopian high lands cross the border and become internationally significant.

- Baro-Akobo, Abay (Blue Nile) and Tekeze rivers drain west ward into the Mediterranean Ocean.
- Ghenale and WabiShebele Rivers drain east ward into the Indian Ocean.

- Rift Valley has an inward slopping resulting mainly in an inland drainage System

2.2.4. Wetlands



Wetlands are dynamic; they change seasonally with changes in annual precipitation. Wetlands with static water levels tend to become more pond like and lose some of their Wetlands with static water levels tend to become more pond-like and lose some of their ecological value. Many wetland plants and animals are adapted to the periodic saturation and drying that occurs and small changes in flood/dry patterns can drastically change plant and animal species composition.

In Ethiopia wetlands are distributed all across the topographic unit of the country ranging from the lowlands of salt lakes in the Afar depression to the freshwater shallow lakes at Bale and Semen Mountains. They are estimated to constitute 2% of the total area of the country.

Swamps and marshes are the predominant forms often identified by reference to vegetation locally known as "cheffe", which is the typical vegetation in most wetlands. Marshes are periodically saturated, flooded, or opened with water and characterized by herbaceous vegetation adapted to wet soil conditions. Swamps are, however, fed primarily by surface water inputs and are dominated by trees and shrubs. They are characterized by very wet soils during the growing season and standing water during certain times of the year.

Wetlands are most productive environments important in:

- Maintaining key ecological processes (reduce siltation, purifies water, ground water recharge and discharge, etc)
- Supporting high biodiversity (such as waterfowl, mammals, reptiles, amphibians, fish and invertebrate species, medicinal plan species)
- Providing socio-economic benefits to local communities

In Ethiopia, the socio-economic benefits of wetlands include:

- Provision of clean water supplies throughout the year
- The wetland vegetation, such as "cheffe", reeds, palms, bamboos and papyrus, etc are harvested by the local people for roofing and making of various crafts including boats.
- The other wetland plants, such as Hygrophilaauriculata (locally known as balanworanti) are used for medicinal purpose
- Most wetlands are used for cattle grazing and watering
- Wetlands are also used to cultivate maize and other edible plants during dry season.

Chapter Review Questions

Answer the following questions properly. Refer to the appropriate sections to confirm your answers

1. What is catchment or drainage basin?
2. List down the seven Ethiopian drainage basins.
3. Categorize the Ethiopian drainage basins into their respective topographic regions. What are the three Ethiopian drainage topographic regions?
4. Give examples of rivers and lakes located in each basin
5. Which of the Ethiopian lakes and rivers are mainly important in fisheries?
6. What are the differences between the endorheic and exorheic drainage basins?
7. Which of the Ethiopian drainage basins are endorheic? Exorheic?
8. What is watershed? Give examples
9. List down the various catchment characteristics that can affect the various aspects of a water body located in a giver drainage basin.
10. What are the characteristics of Ethiopian rivers in terms of the amount of water and flow pattern?
11. Why are the Ethiopian rivers said to be highly erosive?
12. Which wetland types are much common in Ethiopia?
13. What the various ecological functions of wetlands? Their socio-economic functions?

Chapter 3
Ecology of Aquatic Ecosystems

3.1. Zonation's in Aquatic Ecosystems

3.1.1. Zonation's in Freshwater Ecosystems

Deep lakes are often divided in to some horizontal and vertical distinct zones.

The littoral zone is shallow, well-lighted, warm water close to shore. It is usually rooted and floating plants flourish, but in some lakes aquatic plants (macrophytes) may be completely lacking, such as in circular, cone-shaped crater lakes. This is usually because of poor catchment or steep littoral. Its characterized by the presence of rooted and floating vegetation, a diverse attached algae community, and a very diverse animal fauna including suspension feeders (e.g. clams), herbivorous grazers (e.g. snails), and herbivorous and carnivorous insects, crustaceans, fishes, amphibians, some reptiles, waterfowl, and mammals.

Photic (euphotic) zone is the upper layer in the limnetic zone where light is sufficient enough for the rate of photosynthesis to exceed the rate of respiration. Aphotic (dark) zone is the lower zone that receives little or no light, due to the absorption of light attenuation in the upper water column, and no photosynthesis occurs.

The limnetic zone is the open, well-lighted waters away from the shore occupied by phytoplankton (algae and cyanobacteria) which are photosynthetic, zooplankton, higher animals and produces food and oxygen that supports most of lake's consumers. This zone could be small or large, depending on the surface area of the lake. zooplankton (rotifers and small crustaceans) that grazes on phytoplankton, and small fish that feed on the zooplankton. Occasionally large fish, turtles, snakes, and piscivorous birds are also seen in this zone.

The profundal zone is the deep, aphotic zone lying beneath the limnetic zone where water temperature is usually cold. This is an area of decomposition where detritus is broken down; thus, oxygen is low and mineral nutrients are usually plentiful due to cellular respiration of decomposers. Waters of the profundal zone usually do not mix with surface waters because of density differences related to temperature. Mixing of these layers usually occurs twice each year in temperate lakes and ponds; this results in oxygen entering the profundal zone and nutrients being cycled into the limnetic zone.

The benthic zone is the bottom of the lake and is inhabited by organisms that can tolerate cool temperatures and low oxygen levels. The food source is detritus which animals feed on in different ways. Diversity of animals and plants is low in this zone, but the abundance and biomass of a few species could be very high. Insect larva and some oligochaetes are abundant here.

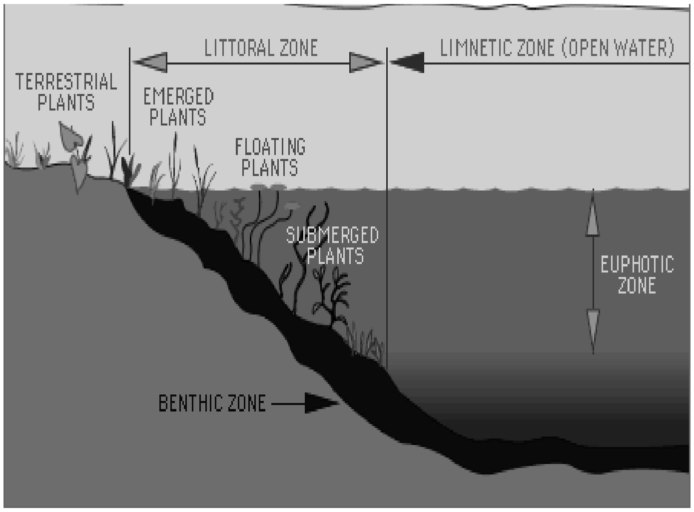


Fig.3.1. the different zones in a lake

3.1.2. Zonation's in Marine Ecosystems

There are several zones in the ocean based on depth of water, degree of light penetration, distance from shore and open water versus bottom area. The marine ecosystems can be divided into various horizontal and vertical zones such as intertidal (littoral), neritic, oceanic, etc as described below.

Intertidal zone: is where land meets water. This zone is alternately submerged and exposed twice daily due to tides. Animal and plant communities are subjected to huge daily variations in availability of saltwater and temperature. Further, organisms are subject to mechanical forces of wave action because the habitat can be rocky or sandy. Consequently, organisms inhabiting this zone have adaptations that enable them to survive periodic exposure to the air and wave action. Examples of habitats occurring in this zone include mangrove swamps, sea grasses, coral reefs and sandy beaches. These habitats all come with their unique challenges and are inhabited by a wide variety of organisms and some of these regions are quite productive. Due to extensive human habitation in this zone, the biota is often destroyed by pollution, sedimentation and human activity. These include Mangrove, Sea grass, Coral reefs and Rocky inter tidal zones.

- **Mangrove** is a marine a habitat comprised of a number of salt-tolerant (halophytic) plant species, of which there are more than 12 families and 50 species worldwide. Mangrove plants have a tangle of roots which are often exposed above water, leading to the nickname "walking trees." The roots of mangrove plants are adapted to filter salt water, and their leaves can excrete salt, allowing them to survive where other land plants cannot**.**

  Mangroves are important marine habitats providing food, shelter and nursery areas for fish, birds, crustaceans and other marine life.
- **Sea grass** is a flowering plant (angiosperm) that lives in a marine or brackish environment. There are about 50 species of true sea grasses worldwide. Sea grasses are found in protected coastal waters such as bays, lagoons, and estuaries and in both temperate and tropical regions. Sea grasses attach to the ocean bottom by thick roots and rhizomes, horizontal stems with

shoots pointing upward and roots pointing downward. Their roots help stabilize the ocean bottom. Sea grasses provide an important habitat to a number of organisms. Some use sea grass beds as nursery areas, others seek shelter there their whole lives. Larger animals such as manatees and sea turtles feed on animals that live in the sea grass beds.

- **Coral reefs** are marine habitats formed by hundreds of coral species found in the world's oceans in littoral. There are two types of corals: hard corals and soft corals. Only hard corals build reefs. While the majority of coral reefs are found in tropical and sub-tropical water within the latitudes of 30 degrees north and 30 degrees south, there are also deep-water corals in colder regions. Coral reefs are complex ecosystems supporting a wide array of marine species. The largest and most well-known example of a tropical reef is the Great Barrier Reef in Australia.

- **Rocky intertidal zones** are vertically stratified and inhabited by organisms that possess structural adaptations that allow them to remain attached in this harsh environment. The uppermost zone is submerged only by the highest tides and is occupied by relatively few species of algae, grazing mollusks, and suspension-feeding barnacles; these organisms have various adaptations to prevent dehydration. The middle zone is exposed at low tide and submerged at high tide; many species of algae, sponges, sea anemone, barnacles, mussels, and other invertebrates are found in this area. The diversity is greater here due to the longer time spans this area is submerged. Tide pools are often found in the middle zone. These are depressions which are covered during high tide and remain as pools during low tide; tide pool organisms face dramatic salinity increases as water evaporates at low tide. The low intertidal zone is exposed only during the lowest tides and shows the greatest diversity of invertebrates, fishes and seaweeds.

The Neritic zone extends beyond intertidal and includes shallow regions over the continental shelves. In warm tropical waters, this region contains coral reefs dominated by structure of coral itself. Coral reefs are formed by diverse group of cnidarians that secrete hard external skeletons made of calcium carbonate and are assisted in the process by photosynthetic symbionts living in the body wall (called zooxanthellae and zoochlorellae). Primary productivity here depends on planktonic algae growing as deep as the light can reach. The neritic zone is very productive because currents and waves constantly and renew nutrients light penetrates to ocean floor allowing photosynthesis. But this zone is easily degraded by pollution, development and high-water temperatures.

The oceanic pelagic zone extends past continental shelves, can be very deep, is the open water and includes most of the ocean's water. This zone is constantly mixed by ocean currents and because there is no place to sit on, tiny floating plants and animals called plankton live in the lighted area (photic zone) here. Nutrient concentrations are generally lower than in coastal areas. In this zone despite its diversity of life, primary productivity is much limited to the depths that light can reach. The producers are planktonic algae that support secondary and higher consumers (e.g., fish) in the nekton. Besides plankton, this zone is home for a great variety of free-swimming animals (fish, large squid, sea turtles, marine mammals).

The benthic zone consists of the ocean bottom below neritic and oceanic pelagic zones(deep sea) includes the deepest, darkest, coldest parts of the ocean. In this zone are found unique habitats namely the **hydrothermal vents** that remained unknown until about 30 years ago, when they were discovered in the submersible Alvin. Hydrothermal vents are found at an average depth of about 7,000 feet and are essentially underwater geysers created as a result of cracks in the ocean floor due to the movement of plate tectonics. Ocean water enters these cracks, is heated up by the Earth's magma, and then released through the hydrothermal vents, along with minerals such as hydrogen sulfide. The water coming out of the vents can reach incredible temperatures of up to 750 degrees F. Despite their threatening description, hundreds of species of marine life thrive in this habitat. The main food source are the dead organic matter and nutrients "rain" down from above in form of detritus. The communities consist of bacteria, fungi, seaweed and filamentous algae, numerous invertebrates, and fish.

The abyssal zone is the deepest part of the ocean below 4 km and is **home of** deep benthic communities. organisms here are adapted to continuous cold, high pressure (hydrostatic), low to no light (aphotic) and low nutrients. Despite these stresses, deep-sea also *hydrothermal vents* of volcanic origin are found here and some bacteria which can metabolize simple molecules such as H_2S, CO_2 are found here. These producers are called *chemoautotrophs.*The abyssal zoneis the bottom of the ocean basins which is relatively unvarying region largely inhabited by sparse populations of bottom-dwelling organisms that make up the benthos. These are consumers and decomposers which depend on the organic matter drifting down from the upper portions of the sea.

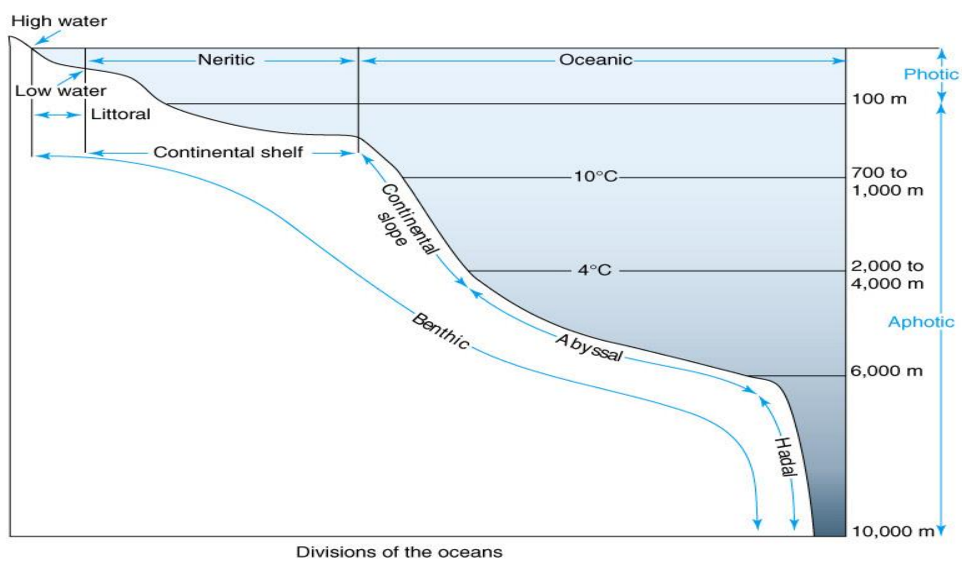


Fig. 3.2 Major zones in the oceans (note vertical and horizontal distribution)

3.2. Autochotonus and Allochtonous Inputs

Autochthonous inputs refer to the organic production within the water body as a function of the primary producers such as phytoplankton. This is the major source of organic supply to the life in the aquatic habitats. On the other hand, allochtonous input refers to organic materials (such as leaves, branches and dead bodies) washed into the system. Allochtonous inputs provide an important food source, especially where dense vegetation along the shore blocks out sunlight or high turbidity prevents light penetration.

3.3. Community Structure

Classes of organisms found in aquatic ecosystems can be categorized as **plankton, nektons and benthos**

3.3.1. Plankton community

The term plankton is derived from the Greek word “planktos”, meaning “drifter" to indicate their movement which is largely dependent on water currents. Plankton are any driftingorganisms including animals, plants or bacteria that inhabit the pelagic zone of aquatic ecosystems. While some forms are capable of independent movement and can swim hundreds of metersvertically in a single day (Diel Vertical Migration), their horizontal position is primarily determined by the surrounding water currents. They provide a crucial source of food to larger aquatic organisms such as fish. Moreover, theyare important in the biogeochemical cycles of many important chemical elements including carbon.

In a plankton community two forms can be recognized: holoplankton and meroplakton. Plankton such as most algae, copepods, salps and jelly fish spending their entire life as plankton aretermed as holoplankton. In contrast, those which are planktic only for part of their lives, such as the larval stages of fish, crustaceans, starfish, etc, are known as meroplankton.

Plankton abundance and distribution are strongly dependent on factors such as ambient nutrients concentrations, the physical state of the water column, and the abundance of other plankton. Local abundance varies horizontally, vertically and seasonally primarily because of the availability of light.

The term “vertical” refers to variation at different points along the depth (i.e. from top to bottom or bottom to up) and “horizontal” refers to variation along the length or the width of the water body. All plankton ecosystems are driven by the input of solar energy (except thechemosynthetic forms), confining primary production to surface waters, and to geographical regions and seasons having abundant light. A secondary variable is nutrient availability. For example, although large areas of the tropical and sub-tropical oceans have abundant light, they experience relatively low primary production because they offer limited nutrients such as

nitrate, phosphate and silicate resulting from large-scale ocean circulation and water column stratification

- **Trophic Groups of Plankton**

  Plankton can be divided into some functional or trophic level groups.

Producer plankton are those capable of transforming inorganic nutrients ($CO2$ and $O2$) into organic materials (e.g. carbohydrates) using either sunlight (photosynthetic plankton) or chemical energy (chemosynthetic plankton). These are therefore the primary producers in aquatic environments, which are equivalent to the “green plants” in terrestrial ecosystems. On the other hand, heterotrophic plankton are those which are not capable of converting inorganic substances into organic substances. The heterotrophic plankton can be either consumer or decomposer (recyclers). These major plankton categories (i.e. autotrophic and heterotrophic) are divided into functional or trophic level groups though the determination for some plankton may not be straightforward. For example, although most dinoflagellates are photosynthetic producers or heterotrophic consumers, many species are mixotrophic (i.e. both photosynthetic and heterotrophic) depending upon circumstances. The following are the major categories of plankton**: Phytoplankton(microscopic plants), Zooplankton(microscopic animals) and Bacterioplankton.**

Phytoplankton(from Greek phyton, or plant), autotrophic, prokaryotic or eukaryotic algae that live near the water surface where there is sufficient light to support photosynthesis. Phytoplankton are plant like photosynthetic microorganisms adapted to live freely drifting within the main water body of aquatic systems such as freshwater, marine water and estuaries. They live, wholly or partly, in the open water and are carried by the water currents.

Phytoplankton are the main primary producers and hence energy sources in the aquatic food web and equivalents of plants in terrestrial food web. They are composed of organisms from different kingdoms and size groups. Among the more important groups are the diatoms, cyanobacteria, dinoflagellates and cocolithophores Some phytoplankton are prokaryotic bacteria (cyanobacteria) while others are eukaryotic algae. They don't have differentiated plant structures such as roots, stems or leaves.

Phytoplankton (algae) show diversity in size and morphology. They can occur as single cell, colonial or filamentous forms, and can be motile or non-motile. They vary in size ranging from 0.2 μm to 1 cm and which can be categorized into various size classes based on their cell size (diameter): picoplankton (< 2 μm), nanoplankton (2 – 20 μm), microplankton (20 – 200 μm) and macroplankton (>200 μm). Phytoplankton also show taxonomic diversity and the major divisions, for example, include Chlorophyta (green algae), Cyanophyta (blue-greens), Dinophyta (dinoflagellates), Bacillariophyta (diatoms) and so on.

Some benefits of phytoplanktonas primary producers in aquatic food web (food source, carbon dioxide recycle and oxygen release)

Phytoplankton are the base of food web in the aquatic ecosystems, providing energy sources for all organisms in the system. The existence of the smallest animals or consumers (e.g. zooplankton) to largest mammals (e.g. whale) living in the water is due to the phytoplankton. Half of the photosynthetic production on earth is accounted for by the phytoplankton. In addition to serving as a food source, phytoplankton play an important role in the global carbon-cycle. Through photosynthesis, they fix carbon dioxide, the main greenhouse gas, and convert to organic carbon. In this process, they can consume carbon dioxide equivalent to that taken up by land plants and thus contribute a lot to regulation of global warming. During photosynthesis, they also release a lot of oxygen, which account for about half of the total amount of oxygen produced by all plants on earth.

Food and chemical sources

Several species of phytoplankton have been used as food and valuable chemical sources. The cyanobacterium Spirulina (Arthrospira), for example, is well known species used as food for humans and other animals due to its best nutritional qualities and as sources of chemicals of high pharmaceutical values. Spirulina contains rich sources of protein, accounting for up to 70% crude protein (of dry weight) with balanced proportion of amino acids. It also contains rich sources of vitamins (e.g. beta-carotene and B12), minerals (e.g. iron), fatty-acids (e.g. gamma-linolenic acid), essential amino acids and the pigment phycocyanin. Due to these facts, WHO and other world organizations consider Spirulina as the best nutrition to combat hunger and malnutrition. Several big business companies around the world, Earthrise Nutritionals and Cyanotech in USA, for example, are currently engaged in producing and selling Spirulina as food supplements. Spirulina is abundantly found in some natural soda lakes of Ethiopia such as Lake Chitu. There are several other phytoplankton such as Dunaliella, Haematococcus, Chlorella, etc., which are widely cultivated to produce various high-value compounds such as carotenoids, beta-carotene (from Dunaliellasalina) and astaxanthin (from *Haematococcuspluvialis)* and food supplements.

Biofuel production

Algae-based biofuel production has now received worldwide interest in developing green economy using renewable and cleaner biofuel sources. It has been confirmed that, compared to terrestrial oilseed crops such as soybean and canola, algae are capable of producing 40 times the amount of oil for biodiesel per unit area of land under controlled conditions. As a result, many algae biofuel companies are expanding rapidly around the world. Some examples of algal genera or species with high oil content and potential for biofuel include *Botryococcus braunii*, *Nanno chloropsis*, *Hantzschia*, *Chlorella*, *Scene desmus*, *Cyclotella*, *Nitzschia*. These and others are cultured in various cultivation systems (open ponds or bioreactors) and their biomass harvested is used to produce biofuel including biodiesel, ethanol, methane, hydrogen and other hydrocarbon fuels.

As indicators of environmental changes

Phytoplankton are sensitive and quickly respond to changes in water quality and thus can serve as bioindicators, a particular species or community that provide information on surrounding environment. Occurrence of a particular species in high abundance, a phenomenon known as a bloom, indicates changes in water conditions. Dominance of a specific cyanobacterial species (*Microcystis*) in freshwaters, for example, is indicative of eutrophication and increase of temperature of the water body. Eutrophication is an enrichment (excessive loading) of the water body with the major algal nutrients such as phosphorus and nitrogen, mainly caused by human activities. Such blooms have disastrous effects to the ecosystems: blocking of penetration of light to the bottom, causing fish kill due to depletion of oxygen caused by decomposition of the collapsed bloom, releasing toxins to the water column, impairing recreational activities and the like. Some species of the phytoplankton such as certain dinoflagellates and blue-green algae (cyanobacteria) can produce harmful algal blooms with powerful biotoxins, which are toxic to aquatic as well as terrestrial animals including human beings.

The phytoplankton diatoms are also often used as bioindicators for study of environmental conditions. Several diatoms are used as indicators of contemporary ecological conditions because of their ecological preference (tolerance) to certain environmental conditions such as turbulent water, nutrients, organic pollutions, salinity, pH and heavy metals. Benthic diatoms are often used for assessment of water quality in rivers and many indices have been developed to use diatoms as water quality indicators. In addition, diatoms are used to obtain information on past water quality or ecological conditions (reference conditions or earlier situations when there was insignificant anthropologic influence) from lake sediment analysis of their fossils (palaeolimnological study). The formation of fossils of diatoms is because of their thick silica cell wall (frustule), which is resistant to biodegradation. Lake sediment diatom analysis is used to assess problems of surface water acidification, eutrophication and climate change. In general, the knowledge and information from the bioindicator species is useful to monitor the aquatic environment and to prevent or reduce the problems.

Algae-based wastewater treatment (bioremediation)

Phytoplankton are nowadays considered useful organisms in algae-based treatment of various kinds of municipal and industrial wastewaters. Some species like *Chlamydomonas*, *Scenedesmus*, *Chlorella*, *Pondorhina*, *Euridina*, etc. are living in wastewater (sewage water) and are important bioremediation agents. They are mainly useful to clean the water by supplying oxygen to the aerobic bacteria (decomposers) through photosynthesis and consuming the nutrients (mainly CO_2, nitrogen and phosphorus materials) in the wastewater. In such systems, algae also remove toxic heavy metals and reduce odor from the wastes.

In general, studying phytoplankton is one of the basic and applied scientific fields, enabling one to entertain ecological, environmental and economic issues. Presently, increased deterioration of water bodies and climate change associated with increased pressure from human activities has further made phytoplankton studies of utmost importance.

Size Classes of Plankton

Group	Size range	Examples
Megaplankton	2×10−2 m (20+ mm)	Metazoans such as jellyfish, ctenophores, salps and pyrosomes (pelagic tunicata), cephalopoda
Macroplankton	2×10−3→2×10−2 m (2–20 mm)	Metazoans such as pteropods, chaetognaths, euphausiacea (krill), medusae, ctenophores, salps, doliolidsandpyrosomes(pelagictunicata),cephalopoda
Mesoplankton	2×(0.2 mm-2 mm) 10−4→2×10−3 m	Metazoans such as copepods, medusae, cladocera, ostracoda, chaetognaths, pteropods, tunicata, heteropoda

Microplankton	2×10−5→2×10−4 m (20-200 µm)	Large eukaryotic protests, most phytoplankton, protozoa (e.g. foraminifera), ciliates, rotifera, juvenile metazoans-crustacean (e.g. copepod nauplii)
Nanoplankton	2×10−6→2×10−5 m (2-20 µm)	Small eukaryotic protests, small diatoms, small flagellates,Pyrrophyta,cryophyte, Chlorophyta, xanthophyte
Picoplankton	2×10−7→2×10−6 m (0.2-2 µm)	Small eukaryotic, protists, bacteria, chrysophyta
Femtoplankton	< 2×10−7 m (<0.2 µm)	Marine viruses

Many planktonic organisms are microscopic and a few also comprise organisms covering wide range of sizes including large organisms. Plankton are often described in terms of size as summarized in the following table.

Zooplankton (from Greek zoon, which means animal), small protozoans or metazoans (e.g. crustaceans and rotifers) that feed on other plankton. Eggs and larvae of some of the larger animals such as fish, crustaceans, and annelids are included here. Zooplankton are the initial prey item for almost all fish larvae as they switch from their yolk sacs to external feeding. Fish rely on the density and distribution of zooplankton to match that of new larvae, which can otherwise starve. Natural factors (e.g., current variations) and man-made factors (e.g. river dams) can strongly affect zooplankton, which can in turn strongly affect larval survival, and therefore fish breeding success.

Bacterioplankton are bacteria and archaea which play an important role in remineralizing organic material down the water column.

3.3.2. Nekton and Benthic communities

Organisms such as fish that can swim against the water current and control their position are termed as nekton. Nektons are usually swimmers in the water column and they generally represent secondary productivity in aquaticecosystems. On the other hand, benthos are those organisms inhabiting the bottom of the aquatic habitat.

3.4. Aquatic Ecology

3.4.1. Abiotic Components

Abiotic factors such as temperature, precipitation, and light influence the distribution of organisms. The patchiness of the global biosphere illustrates how the different physical environments produce a mosaic of habitats. Some of the important abiotic factors that affect distribution of species have been described in section 1.2. in chapter 1.

3.4.2. Functional Feeding Groups

- **Autotrophic Groups**

Autotrophic organisms are producers that generate organic compounds from inorganic materials. These are largely phytoplankton (algae) that use solar or chemical energy to generate biomass from carbon dioxide. Photosynthetic organisms are the major autotrophs in aquatic ecosystems whereas chemosynthetic organisms (e.g. some bacteria) are largely benthic in aquatic ecosystems.

Aquatic rooted plants such as weeds and also some bacteria (photosynthetic and chemosynthetic bacteria) also contribute to aquatic primary production.

Heterotrophic Groups

Heterotrophic organisms derive their organic nutrient need from autotrophic organisms either as consumers or decomposers. Consumers are largelyzooplankton and nektons such as fish whereas decomposers include some bacteria.

Primary production in the pelagic zone of the oceans is the result of photosynthetic activity of phytoplankton. Zooplankton graze on smallerphytoplankton. Phagoplankton are another form of heterotrophic forms of plankton assimilate dissolved organic material from the water. The oceanic food web is largely plankton-based whereas in freshwaters (e.g. some lakes, rivers and streams) food web weeds are also important bases in addition to phytoplankton. Zooplankton and phagoplankton are, in turn, consumed by small invertebrates and fish. Aquatic food web can be represented by the following figure (Fig.3.3).

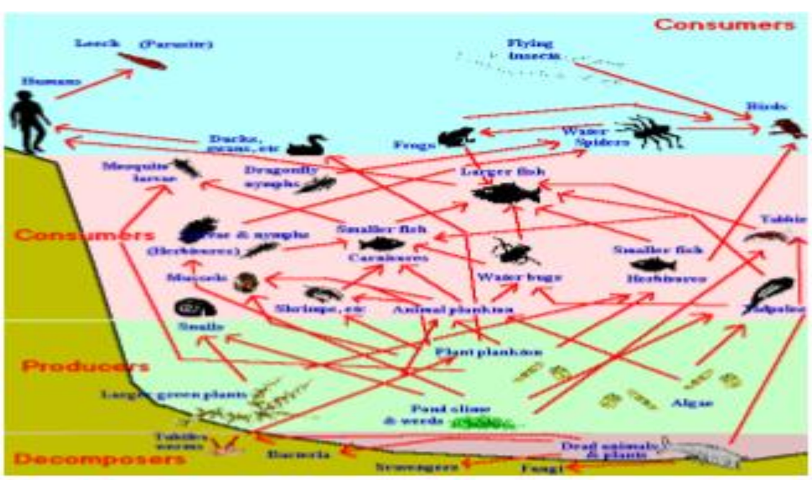


Fig. 3.3 General Representation of Aquatic food web

Chapter Review Questions

Answer the following questions properly. Refer to the appropriate sections to confirm your answers

1. Define each of the following terms in relation to zonations in lakes: (Littoral, Limnetic, Profundal, Euphotic (Photic), Aphotic)

2. Define the following terms in relation to zonations in marine habitats (Littoral, Intertidal, Oceanic, Pelagic, Euphotic, Aphotic, Abyssal plain, Benthic)

3. Give examples marine littoral marine habitats. Briefly describe each of these habitats.

4. What is the difference between autochtonous and allochtonous inputs in aquatic ecosystems? Give examples for each.

5. What are plankton, neckton and benthos in aquatic ecosystems?

6. What are the differences between holoplankton and meroplankton? Give examples

7. What are the differences among producer, consumer and decomposer plankton? Give examples for each?

8. What are the differences between photosynthesis and chemosynthesis? Give examples of organisms carrying out each activity.

9. Distinguish between Zooplankton, Phagoplankton, Phtoplankton and Bactrioplankton with their functions and examples.

10. List down the seven size classes of plankton described in the chapter with at least on example

11. What are the major primary producers in aquatic ecosystems? Phytoplankton or rooted aquatic plants?

12. In which of the aquatic ecosystems (Oceans, lakes or rivers) are the rooted aquatic plants more important as primary producers?

13. What are factors that can affect the abundance and distribution of plankton in aquatic ecosystems?

Chapter 4: Water Pollution

4.1. What is Water Pollution?

There exist various definitions of water pollution. Some, for instance, define water pollution as: “the introduction by man, directly or indirectly, of substances or energy into the aquatic environments resulting in such deleterious effects as harm to living resources, hazards to human health, hindrance to aquatic activities, including fishing, impairment of water quality with respect to its use in agriculture, and often economic uses". Others define water pollution as a "state resulting when substances are released into a body of water, where they become dissolved or suspended in the water or deposited on the bottom, accumulating to the extent that they overwhelm its capacity to absorb, break down, or recycle them, and thus interfering with the functioning of aquatic ecosystems".

Given the various ways of defining water pollution, it, however, refers to the contamination of both the surface water and groundwater. Surface water includes the visible water resources, such as oceans, rivers and lakes, that are found on the exterior of the earth's crust. Groundwater, however, is a water resource found underground in rock structures called aquifers. Groundwater is important for recharge of surface waters and supplies much of drinking water. Though groundwater pollution is much less obvious than surface-water pollution, but is no less of a problem. Surface water resources are more vulnerable to pollution. Moreover, factors that lead to surface water pollution may not lead to groundwater pollution and vice versa. Also the management of groundwater pollution is more difficult.

4.2. Sources of Water Pollution

Water pollution can occur due to natural or anthropogenic (i.e. human induced) factors. Natural factors such as dissolution of rocks and evaporation lead to increased salinity and introduction of heavy metals such as Pb, Hg, Cd and As. The high fluoride content in drinking water leads to conditions such as dental and bone fluorosis whereas the heavy metals are toxic both to human and the environment in various ways.

Industrialization and agricultural activities amalgamated with an alarmingly increasing human population are among the anthropogenic factors that significantly contribute to water pollution. According to the World Population Prospects (2008) the current (2010 G.C.) human population is estimated to be nearly 7 billion, which is projected to reach 9 billion by 2050. At present water pollution is becoming such a serious problem in that every continent, from the tropics to the once-pristine polar regions, is getting contaminated.

The human induced water pollution comes from a number of different sources. If the pollution is from a single source, such as an oil spill or a factory discharging its waste through a pipe into a water body, it is called point-source pollution. On the other hand, if the pollution is caused from many sources, it is called nonpoint-source (diffuse) pollution. Point-source pollution often affects the area immediately around the source. For example, when a tanker accident occurs, the oil spill is concentrated around the tanker itself. This is, however, less likely to happen with nonpoint source pollution since the pollutants enter the environment from many different places.

Sometimes pollutions, such as nuclear or radioactive waste, may affect the environment hundreds of miles away from the source; this is called transboundary pollution.

4.3. Types of Water Pollutions and the Contaminants

A particular pollution source usually produces a mix of water pollutants. For instance, a waste originating from industries could consist of chemicals such as heavy metals, oils, microorganisms, etc. Moreover, a given pollutant could come from more than one type of pollution sources. However, for the sake of simplicity we categorize types of water pollutions and the major contaminants as presented below.

1. Domestic and Industrial Pollution

Domestic activities such as washing and toilet flushing, and industrial activities such as manufacturing processes in industries produce a wastewater that contains waste products collectively known as sewage. Sewage is thus a water-carried waste, in either solution or suspension, that is intended to flow away from a community.

Wastewater is largely pure water and is characterized by its volume or rate of flow, its physical condition, its chemical constituents, and the bacteriological organisms that it contains. Sewage practically contains various types of substances including the pharmaceutical drugs, papers, plastics, and other wastes humans flush down their toilets and factories. Moreover, it often carries harmful micro-organisms such as viruses and bacteria into the environment causing health problems such as hepatitis, typhoid, and cholera. Sewage especially from industries may also contain chemicals such as heavy metals including lead and mercury that are harmful to the health of many animals, including humans.

Heavy metals draw attention in that their concentration increases high up in food chain, a condition known as bioaccumulation or bioamplification. The effect of heavy metals is thus highly pronounced at higher trophic levels such as in human being.

If suitably treated and used in moderate quantities, sewage can be a fertilizer: it returns important nutrients to the environment, such as nitrogen and phosphorus, which plants and animals need for growth. The trouble is, sewage is often released in much greater quantities than the natural environment can cope with. Untreated sewage can contaminate the environment and cause diseases such as diarrhea.

Sewage management or disposal is a major problem in developing countries as access to sanitary conditions and clean water in these areas is scarce. Sewage in developed countries is carried away from the home quickly and hygienically through sewage pipes to be treated in water treatment plants and ultimately disposed into the aquatic environments. However, the dumping of sewage into seas and oceans still remains a serious environmental problem especially in developed countries.

2. Agricultural Pollution

Agricultural activities cause the pollution of water through the addition of pesticides, herbicides and nutrients with surface run-offs as described below.

Pesticides and Herbicides

Pesticides and herbicides are chemicals that are used in farming to control insects, weeds and fungi. These chemicals enter water bodies with run-offs causing poisoning of aquatic life such as fish. Subsequently, birds, humans and other animals may be poisoned if they eat infected fish. The high concern with these chemicals is that, similar to the heavy metals, tend to bioaccumlate in nature.

Nutrients

Chemical fertilizers used by farmers add nutrients such as nitrogen (in the form of nitrates) and phosphorus (in the form of phosphates) to the soil which when run-off into nearby lakes, rivers, or oceans cause an increase in nutrient levels of the water bodies. Nutrients are basically essential for plant growth and development. However, the excessively high nutrient enrichment of thewater bodies causes a massive increase in the growth or bloom of algae or plankton, leading to a condition known as **eutrophication**. Eutrophication can be a problem to the aquatic habitats in various ways.

Excessive algal bloom or eutrophication disrupts normal ecosystem functioning and causes many problems. The following are some of the effects of eutrophication in water bodies:

- Excessive weed and algae growth in water can cause a contamination of drinking water and clog filters.
- The algae may use up all the oxygen in the water, leaving none for other aquatic life. Moreover, microorganisms can cause oxygen depletion when decomposing the dead algal body. This in turn results in the death of many aquatic organisms such as fish, which need oxygen in the water to live.
- The bloom of algae may also block sunlight from photosynthetic aquatic plants found at lower depth. Sunlight blocking also has an effect on visual dependent predators living at relatively lower depths.
- Some algae produce toxins that are harmful to higher forms of life. This can cause problems along the food chain and affect any animal that feeds on them. Birds and humans can get poisoned and even die when feed on poisoned fish.

It is important to bear in mind, however, that eutrophication is basically a natural process that can develop because of the vertical mixing of the water bodies (which upwells nutrients from the bottom) and with the ageing of the water bodies, often leading to high aquatic productivity including high fish production. It becomes catastrophic when accelerated because of the human

induced activities.

3. Oil Pollution

Oil pollution is caused by oil spills from tankers, shipping, dumping from factories and surface run-offs. However, the latter three factors account for the larger proportion of oil pollution. Oil spills cause a localised problem but can be catastrophic to local aquatic wildlife such as fish and aquatic birds. Oil cannot dissolve in water and thus forms a thick layer in the water. It consequently suffocates fish, gets caught in the feathers of marine birds stopping them from flying and blocks light from photosynthetic aquatic plants.

4. Atmospheric Deposition

Atmospheric deposition is the pollution of water caused by air. Anthropogenic activities such as coal mining and smelting of ores (e.g. sulfide) cause the pollution of air with products that would subsequently lead to the formation of acids such as sulfuric acids, carbonic acids and nitric acids as shown in thechemical reaction below. These acids will reach into the aquatic environments with the rain, called acid rain.

$2FeS_2+7O_2+H_2O$ $\qquad$ $2FeSO_4+ 2H_2SO_4$

It is important to note that human activities can also cause direct acidification such as through addition of battery acid in to water bodies. Acidification of aquatic environments has a sterilizing effect on water as fishes become too weak to survive, and lose their capacity to reproduce normally.

5. Thermal Pollution

This is an increase in water temperature as a result of discharge of hot effluents from sources such as factories and power plants into the water bodies especially into the rivers or naturally caused by global warming. Global warming is a process where the average global temperature increases due to the greenhouse effect. The burning of fossil fuel releases greenhouse gasses, such as carbon dioxide, into the atmosphere causing heat from the sun to get ‘trapped’ in the earth’s atmosphere and consequently the global temperature rises.

An increase in water temperature can result in the death of many aquatic organisms and disrupt many aquatic habitats. For example, it can cause bleaching of coral reefs around the world. Coral reef bleaching is when the coral expels the microorganisms of which it is dependent on. This can result in great damage to coral reefs and subsequently, all the marine life that depends on it. Moreover, it reduces the amount of dissolved oxygen in the water, thus also reducing the level of aquatic life that the aquatic environment can support including fish.

6. Suspended Matter Pollution

Suspended matter in water bodies basically consists of clay, silt, sand, organic compounds, plankton and other microscopic organisms. Such particles vary in size from approximately 10 nm in diameter to 0.1 mm in diameter, although it is usually accepted that suspended matter is the fraction that will not pass through a pore diameter size of 0.45 µm filter.

Suspended matter often originates from surface of the catchment area, eroded from river banks, lake or ocean shores and re suspended from the bed of the water body. Suspended matter can be detrimental to the aquatic environments in various ways. For instance,

- Suspended matter may be responsible for transporting pollutants such as heavy metals.

- ❖ The suspended matter causes the water to become cloudy limiting the depth of sunlight penetration. This hampers aquatic photosynthesis which in turn can disrupt the functioning of the whole aquatic ecosystem.
- ❖ The suspended particles can cause siltation at the bottom which is harmful to the benthic aquatic life.
- ❖ Toxic chemicals suspended in water can be harmful to the development and survival of aquatic life.

When land is cleared of forests, it not only destroys the habitat, but also it can affect the area in other ways. The cleared land becomes exposed, without roots of plants to hold on to the soil, wind and rain will move large amounts of soil from the ground into water bodies, polluting the water.

7. Radioactive wastes pollution

The radioactive (nuclear) wastes largely originate from developed countries and carried around the world when dumped into the sea. The following are some of the major sources of nuclear (radioactive) wastes:

- ❖ Nuclear-fuel reprocessing plants such as in northern Europe (England & France) are the biggest sources of man-made nuclear wastes in the surrounding ocean. Radioactive wastes from these plants have been reported to pollute the down stream countries such as Norway andIreland. Reports also indicate that traces of radioactive pollution have been found as far away as Greenland.
- ❖ Mining and refining of uranium and thorium are also causes of marine nuclear wastes.
- ❖ Radioactive wastes are also produced in the nuclear fuel cycle which is used in many industrial, medical and scientific processes.

Nuclear wastes can have serious detrimental effects on aquatic habitats especially the marine habitats which are the main targets. They can cause cancer and other diseases at lower concentrations and death at higher concentrations. Nuclear wastes can also be threat to the groundwater when injected deep into the earth as an alternative way of dumping them.

8. Alien (exotic) species

Most of the time our perception of water pollution involves things like sewage, toxic metals, or oil spill etc described above from 1 to 7 under section 5.3. However, the introduction of alien species into a given water body can cause a serious problem both on the organisms naturally living in that water body and the aquatic habitats. Alien species (sometimes known as invasive species) are animals or plants from one region that have been introduced into a different ecosystem where they do not belong. Outside their normal environment, they have no natural predators so they rapidly run wild, crowding out the usual animals or plants that thrive there. Alien invaders cancause economic loss when they affect the aquatic habitat or its biota.

A fish known as common carp has been introduced to some of the Ethiopian waters but are generally described invasive in most of the countries.

4.4. Forests and Water Quality

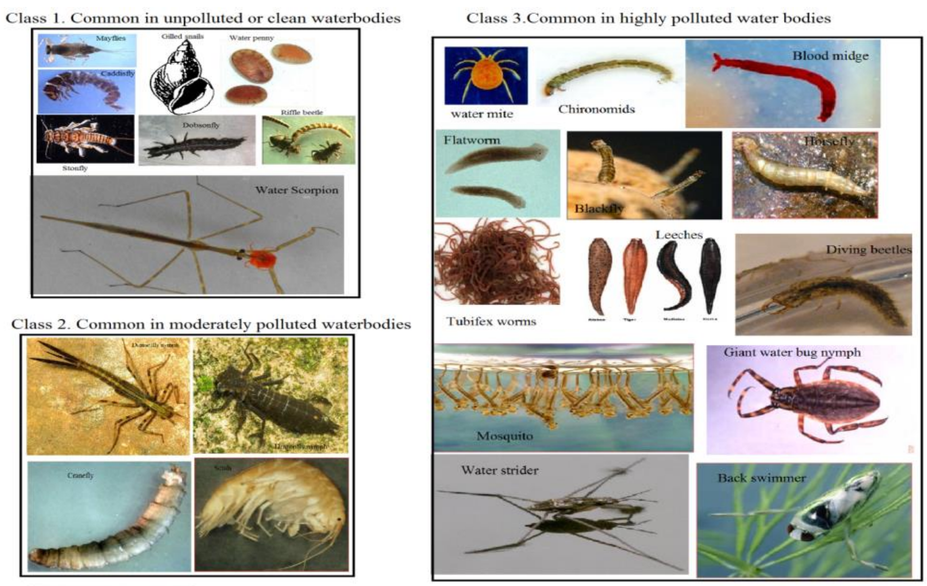
Forests make a significant contribution to maintaining high water quality in watersheds by preventing soil erosion. Forests are more effective than other types of land cover in preventing erosion as roots, undergrowth and forest litter trap sediment. Especially on slopes, trees play a key role in preventing landslides and downward soil movements, lessening the impact of raindrops with their lower canopy leaves. Pollution from diffuse sources i.e. non-point source pollution, such as industrial and agricultural activities, can be reduced by maintaining forests in riparian zones along watercourses.

In contrast, deforestation increases the flow of surface water and transports sediment to streams, silting them up and affecting water quality downstream. Forests can protect watersheds from pollution, caused by chemicals from agriculture and industry, or heavy concentrations of organic matter, which cause eutrophication. The United Nation's Food and Agriculture Organization (FAO) maintains forests as the safest land-use type in drinking-water catchments, as forestry does not normally involve the use of pesticides or fertilizers.

Thus, as population growth increases concerns about depleting freshwater resources increases calling for policymakers to consider integrated water management plans to incorporate forests. The need to halt deforestation is most often heard in the context of increased carbon emissions contributing to global warming. But as scientific knowledge about the role of forests in managing water, consensus is emerging that tackling the problem is key to securing quality water supplies too.

While the benefits of forests in providing good water quality are generally accepted, controversies exist over how much they affect water quantity. The argument traditionally put forward is that conserving forest cover or afforesting upstream watersheds would improve water availability in lowland areas, where demand from households, industry and agriculture is greatest. Forests function like a sponge, regulating the water cycle by absorbing rainfall and releasing it regularly, avoiding droughts and floods.

However, more recent reports challenge this assumption, arguing that tree cover can reduce water flow, especially in arid areas. Forests themselves are major consumers of water: the FAO estimates that up to 35% of rainfall is intercepted andevaporated by tropical forest canopies without contributing to soil water reserves.



Chapter Review Questions

Answer the following questions properly. Refer to the appropriate sections to confirm your answers

1. What is water pollution?

2. What are the differences between point source and diffuse source pollution? Give examples.

3. What is transboundary water pollution? Give example.

4. What is surface water? Groundwater?

5. What are the different examples of water pollutants? List them down.

6. Write down the effects of the various pollutants?

7. Is the introduction of alien species to another water body pollution or not? Why?

8. How do forests affect water quality? Water quantity?

Chapter 5: Water Quality Assessment

5.1. Water Quality

Owing to the complexity of factors determining water quality and the purpose of water quality requirement, it can be difficult to give simple definitions for water quality. Nevertheless, water quality can be defined as “a measure of the condition of water in terms of one or more of its physical, chemical and biological characteristics relative to the intended use”. Water quality depends on the local geology and ecosystem, as well as human uses such as sewage dispersion, industrial pollution, use of water bodies as a heat sink, and overuse. It is most frequently measured by reference to a set of guidelines and standards against which compliance can be assessed as described below in section 6.2.

Water quality requirement is generally applicable in various purposes, such as drinking water supply, industrial use, agricultural (irrigation) use, swimming, boating, and aquatic life and fisheries.

5.2. Water Quality Assessment Parameters

Water quality assessment refers to the overall processes of evaluation of the physical, chemical and biological nature of water in relation to natural quality, human effects and intended uses, particularly uses which may affect health of the aquatic system itself**.**

There exist a large number and complex factors that determine water quality, giving us large choice of variables used to describe water quality inquantitative terms. The appropriate choice of variables for any water quality assessment depends on the objectives of the assessment. Broadly water quality assessments can be divided in to two categories: use-oriented and impact oriented. Use-oriented assessments test whether water quality is satisfactory for specific purposes, such as drinking water supply, industrial use, agricultural (irrigation) use and aquatic life and fisheries.

Many waters use have specific requirements with respect to physical, chemical or biological factors. Thus, the quality of water required for a prescribed water use is often defined by guidelines (recommended concentrations) or standards (mandatory concentrations) or maximum allowable concentrations of the contaminants. The World health organization (2008) of the United Nations (UN) has guidelines and standards for various water uses though the concentrations for some variables could vary from country to country.

Variables of water quality can also be selected in relation to pollutant sources such as sewage and municipal wastewater, agricultural activities, industrial effluents and emissions, atmospheric sources, etc.

Basically, a continuous measurement of water quality parameters is important but in practice this is impossible for financial, technical and logistic limitations. Thus, discrete samples because such samples that constitute only a minute fraction of the whole body of water under investigation should be used, and because they are only representative of conditions at the particular time of sampling the interpretation of data arising from such samples requiresgreat care. Generally, factors used in water quality assessment can be categorized as physico-chemical and biological factors.

5.2.1. Physico-chemical Parameters

The physico-chemical assessment is usually based on a comparison of the measurements made with water quality criteria or with standards derived from such criteria. Some of the physico-chemical parameters such as temperature, pH, dissolved oxygen, conductivity, water turbidity or transparency can be made simply on site in direct contact with the water source in question. These are measured using portable water test kits. If portable meter kits are not available, it is also possible to measure some parameters such as dissolved oxygen and conductivity using lab procedures.

Others such as total biochemical oxygen demand (BOD) suspended solids (TSS), total dissolved solids (TDS), nutrients such as phosphates, nitrates, nitrites and ammonia, and metallic and non-metallic elements are necessarily measured in a laboratory setting. These require a water sample to be collected and preserved before the analysis is done in the laboratory. Below only some of the physico-chemical parameters used in the assessment of water quality are discussed.

1. Turbidity

Turbidity is a measure of the extent to which light is either absorbed or scattered by suspended material in water. It can be measured by using a device known as turbidimeter. This instrument measures the amount of scattered lightin a water sample, and in general scattering intensity increases with particle concentration.

The preferred unit to express turbidity is the nephelometric turbidity unit (NTU). The turbidity of a water in-situ (i.e. on site) can also be indirectly inferred from measurements of water transparency.

2. Water Transparency

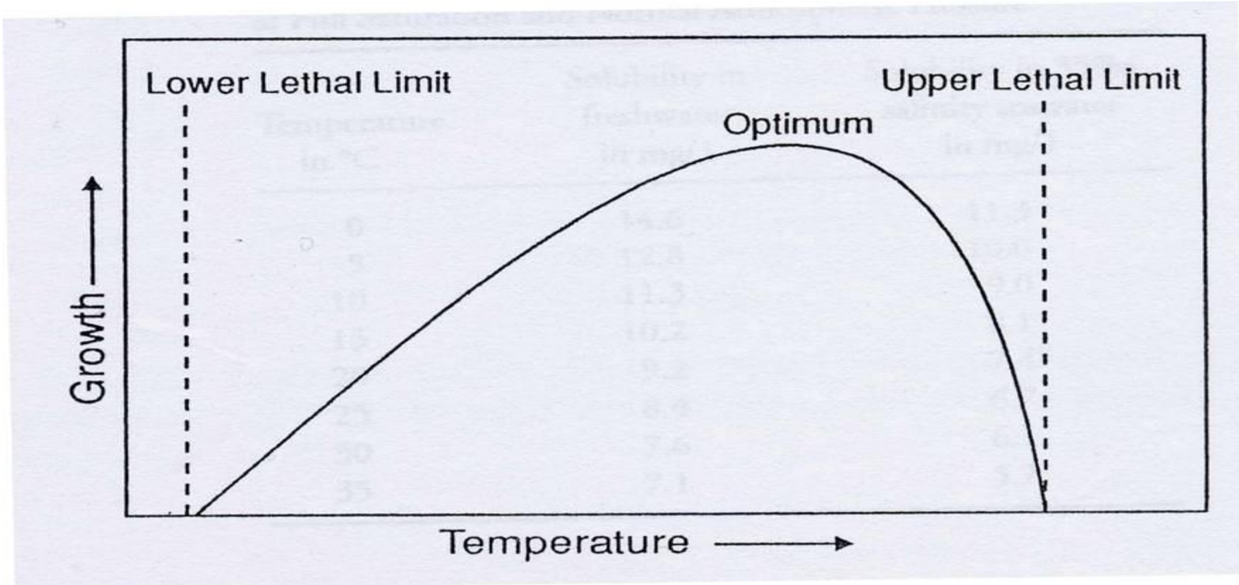
Water transparency is measured using a secchi disk. Secchi disk is a circular disc of usually 20-30 cm in diameter and often painted with black and white sectors (See Fig. 6.1. below). However, the disc diameter does not affect the measurement of water transparency.

Water transparency is measured by lowering a secchi disc on a calibrated cable into the water until it just disappears and then retrieved until it reappears. The depth at which it reappears during retrieval is recorded as a depth of water transparency or secchi depth. Transparency is primarily used as an estimation of primary productivity or phytoplankton biomass.

Fig 6.1. (a) A secchi disc with its cable (b) A secchi disc lowered into water body

3. Temperature

Aquatic organisms are cold-blooded animals. They can modify their body temperature to the environment in normal condition.Each species has a characteristic **temperature range** of optimal feeding, metabolism, growth with **upper and lower lethal limits.**



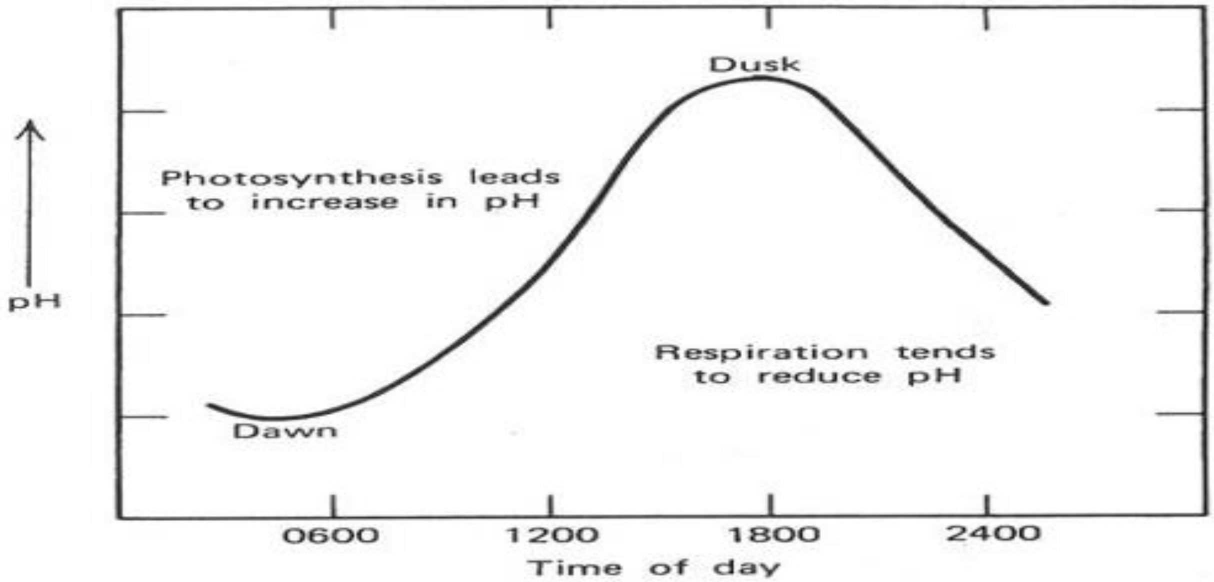
Temperature is an important parameter in natural surface water systems. Temperature of surface waters governs to a large extent the biological species present and their rates of activity. Temperature has an effect on most chemical reactions that occur in natural water systems. Temperature also has a pronounced effect on the solubility of gasses in water. An increases water temperature favor's the conversion of ammonium ion (NH4+) in to ammonium (NH3) which is toxic to the aquatic life including fish. Temperature is often measured by a digital temperature meter.

4. pH

pH is the way of expressing the hydrogen ion activity as a measure of acidity of the water. At a given temperature the intensity of the acidic character of a solution is indicated by **pH** as: **pH** = -log [H+]. **PH** scale is usually represented as ranging from 0 to 14, with **pH** 7 at 25oc representing absolute neutrality, less than 7 represents acidity and greater 7 represents basicity.

water pH fluctuation over 24-hr period

pH diurnal fluctuation pattern that is associated with the intensity of photosynthesis. This is because carbon dioxide is required for photosynthesis and accumulates through nighttime respiration.



pH of the aquatic habitats could vary on a daily basis. During the day time (when concentration of CO_2 is relatively less due to more photosynthesis) **pH** may rise and during night time (when CO_2 concentration is relatively high due to less photosynthesis) it may fall beyond the optimal level and that, in turn, can increase the concentration of the toxic ammonia (**NH_3**). Water **pH** is measured on site using digital **pH** meters.

Water conductivity depends on the presence of ions or salts, their concentration and mobility, and temperature. It is measured using conductivity meter on site and expressed as µmhos/cm or µS/cm. Conductivity is measured as an estimate of dissolved charged atoms or molecules. It is thus used to estimate the total dissolved solids TDS (in mg/L) by multiplying it by a certain conversion factor. Pure water often has less conductivity than polluted water.

6. Nitrogen

Nitrogen is an essential nutrient for algal growth. Nitrogen in water bodies can be measured in the form of nitrogen containing compounds such as ammonia (**NH_3**), nitrate (**NO_3^-**) and nitrite (**NO_2^-**) following standard laboratory procedures. It is expressed as µg/L or mg/L. In the presence of oxygen,ammonia can be converted by microorganisms known as nitrosomonas to nitrite, which in turn is oxidized by nitrobacter to nitrates as shown below. $NH_3 + O_2$ Nitrosomonas <u>$NO_2^- + 3H^+$ Nitrobacter $(+ O_2)$ $2NO_3^-$</u>

7. Phosphate

Phosphorus, together with nitrogen is an essential nutrient for algal growth, and when in excess it is one of the leading causes of eutrophication. The primary sources of phosphorus in natural systems include waste water treatment facilities, runoff of fertilizer from agricultural operations, detergents and some natural sources. It is expressed as µg/L or mg/L.

Orthophosphates and polyphosphates are the most common forms of inorganic phosphorus found in natural waters. Orthophosphates contain a single phosphorus molecule, and common orthophosphates include trisodium phosphate (Na_3PO_4), disodium phosphate (Na_2HPO_4), monosodium phosphate (NaH_2PO_4), and diammonium phosphate ($(NH_4)_2HPO_4$). Polyphosphatescontain multiple phosphorus molecules, and examples include sodium hexametaphosphate ($Na_3(PO_3)_6$), sodium tripolyphosphate ($Na_5P_3O_{10}$), and tetrasodium pyrophosphate ($Na_4P_2O_7$). These are measured using standard laboratory procedures to give a measure of phosphorus in water.

8. Dissolved Oxygen (DO)

Natural levels of dissolved oxygen in surface waters range from 7 mg/L to 14 mg/L, depending on temperature, salt concentration, and the amount of biodegradable organic matter.

When organic pollution is present, for example, due to a combined sewer overflow, microorganisms in the water utilize the available oxygen to convert the organic material to cell mass and carbon dioxide. As a result, the dissolved oxygen concentration can drop to levels significantly below 7 mg/L. Dissolved oxygen in the natural waters can be measured directly on site using appropriate digital oxygen meter or in the lab using titration methods such as Winkler method.

9. Biochemical oxygen demand (BOD)

This is measuring the amount of organic pollution in terms of the amount of oxygen required by microorganisms to biologically degrade organic wastes. Complete stabilization of a waste by microorganisms requires too long incubation period; therefore, the 5-day period has been accepted as a standard.

The 5-day BOD (known as BOD_5) is the total amount of oxygen consumed by microorganisms during the first 5 days of biodegradation. Samples are incubated at 20oC in darkness to prevent algae from adding oxygen to the air tight bottle. The BOD of the water is given by an expression:

- ✓ BOD = DOt0 - DOt5 where DOt0 is the amount of dissolved oxygen (mg/L) of the water at time t = 0 and DOt5 is the amount of dissolved oxygen (mg/L) of the water after 5 days. The amount of dissolved oxygen during the initial (DOt0) and dissolved oxygen after 5-days incubation (DOt5) are measured following standard laboratory procedures.

10. Chemical oxygen demand (COD).

The Chemical Oxygen Demand (COD) is the amount of oxygen needed to chemically oxidize organic wastes in the water under investigation. In the COD test, a strong chemical oxidizing agent is used to oxidize the organics. The primary advantage of COD over BOD is that it is relatively fast, taking 2 to 3 hours, whereas BOD requires 5 days to complete. Another difference in the test methods is that BOD is a biochemical process as measured by the ability of microbes to degrade the organics, whereas COD is purely a chemical process.

5.2.2. Biological Parameters

Aquatic organisms have preferred habitat requirements with respect to the physical, chemical and biological conditions. Variations in one or more of these conditions can result in reduction in species numbers or a change in species dominance or total loss of sensitive species by death or migration.This can be employed to measure water quality of aquatic habitats in one of the two main approaches: methods based on ‘indicator’ organisms and methods based on community structure.

An indicator organism is a species selected for its tolerance or more frequently for its susceptibility to various types of pollutions or its effects. The various groups of organisms used as indicators of water quality include bacteria, algae, macro invertebrates, protozoa, macrophytes and fish. However, the use of each group of organisms has advantages and limitations. In streams, rivers, and lakes, the diversity of fish and insect species provides a good measure of water quality.

Various biotic scores or biotic indices (biotic indexes) are used in order to determine whether the measurement of a certain group of organisms indicate pollution or in order to determine the water quality of the sampled water body. In this course, however, only three biological measurements namely bacteriological, algal (chlorophyll a) and benthic macro invertebrates will be presented and discussed with their specific biotic scores or indices.

1. Bacteriological Analysis

This is a microbiological analytical procedure of analyzing water to identify the type or estimate the number of bacteria present in the water sample in the study of water quality. Bacteriological analysis of water can have two targets: analysis for the indicator organisms or analysis for the pathogens that might cause concern. Indicator bacteria include non-specific coliforms such as Escherichia coli and Pseudomonas aeruginosa that are very commonly found in the human or animal gut and which, if detected, may suggest the presence of sewage.

Indicator bacteria are used because even when one is infected with more pathogenic bacteria, more indicator bacteria are excreted than the pathogens. It is thus logical to deduce that if indicator bacteria levels are low, then pathogen levels will be very much lower or absent, and conversely.

When indicator organisms' levels exceed specific sets, analysis for pathogens may be undertaken using specific culture methods or molecular biology. Bacteriological analysis of water is usually performed using culture, biochemical and sometimes optical methods. Some of the various methods that can be applied in the bacteriological water quality analysis include plate count, multiple tube method, ATP testing, membrane filtration and pour plates. In plate count method bacteria grow in colony on a nutrient medium so that the colony becomes visible to the naked eye and the number of colonies on a plate can be counted.

A culture medium is a substance containing nutrients in which bacteria or other microorganisms or tissues are cultivated for scientific purposes. Typical media used in bacteriological water quality analysis include Plate count agar for a general count or MacConkey agar to count gram-negative bacteria such as Escherichia coli (E.coli).

2. Chlorophyll a Analysis

Chlorophyll a is the most abundant and important pigment which generally constitutes 2 to 5% of the dry weight of an algal cell. Thus, chlorophyll a is often measured to give an approximate indication of total phytoplankton biomass thus the trophic (productivity) status of the water body that could becaused due to nutrient enrichment such as nitrates and phosphates. The higher the chlorophyll concentration is the higher the abundance of the phytoplankton, and conversely.

Chlorophyll a sample are collected and transported to laboratory in black or translucent bags. It is processed immediately up on arrival in the laboratory following standard procedures (e.g. Clesceri*et al.*, 1998).

At the end of laboratory procedures, the amount of chlorophyll a is measured using various methods. However, a method known as spectrophotometery is much commonly used. In this method the amount of light absorbance by chlorophyll a solution is measured using an instrument known as spectrophotometer. Finally, the absorbance values are converted into the chlorophyll a concentrations using standard formula: Chlorophyll a = (26.73 (663a-665b)V2)/(V1) (L) mgm-3

Where, V1 = Volume of sample (m3)

V2 = Volume of extract (L)

L = Light path length of cuvette (cm)

The value 26.7 = the absorbance correction. (Bartram and Balance, 1996).

The trophic status of a water body is estimated from chlorophyll a concentrations in reference to standard trophic classification schemes (See Appendix 3)

3. Benthic Macroinvertebrates

Benthic macroinvertebrates are various groups of invertebrates including flatworms (e.g. planaria), mollusks (e.g. snail) and mainly insects (e.g. caddisflies, dragonflies, etc) that inhabit the floor of the aquatic habitats. These organisms have differing tolerance to water pollution impacts. Some are easily susceptible or sensitive to water pollution, some are partly sensitive and others are tolerant of water pollution impacts.

In assessing any impact of pollution in a given water body using macroinvertebrates one has to collect the organisms following standard field procedures. A kick net or dip net is often used to collect the macroinvertebrates. After collection the macroinvertebrates are sorted usually in the field and then transported to laboratory preserved in 70 % alcohol for identification (using identification keys e.g. Bouchard, 2004) and enumeration.

Different biological indexes and scores of macroinvertebrates are used to interpret the macroinvertebrate data into water quality. Two biological indices namely EPT index and the Chandler biotic index and one scoring system known as the Biological monitoring working party (BMWP) score are attached in Appendix 2.

5.2.3. Sampling of Surface Waters

5.2.3.1. Designing Sampling Programs

In designing water quality sampling programs various factors should be taken in to account. For instance, factors such as sampling techniques, the timing andfrequency of timing, procedures related to sample collection, transport and analysis should be considered.

Ecological methods of water quality assessments can use a wide range of sampling techniques. These include:

- Qualitative technique-e.g. selection of macrophytes by hand
- Semi-quantitative technique-e.g. selection of benthic organisms using a standardized hand net technique
- Fully quantitative technique-e.g. using bottle samples for plankton or grab samples for benthic organisms.

Sampling of parameters, such as macroinvertebrates, is preferable during dry season in tropical climate such as Ethiopia as this timing gives representative samples of the organisms. Most of the time in the study of water quality, the primary goal is to assess the influence of human actions, not the effect of natural variation through time, on aquatic habitats. Thus samples should be collected during a relatively short period.

Moreover, sample collectors should take into account and apply all the procedures associated with the collection and transport of samples to prevent the deterioration of the samples. In general, a well-planned water quality sampling program should have checklist of various items to make sure that noequipment or chemical required for sampling is missing. The water sampling field work checklist should include the following important elements among others:

- Sampling materials
- Documentation materials
- On-site test materials
- Safety materials
- Transport materials
- Calibration of meters and other equipment.

5.2.3.2. Safety in the Field

During water sampling personnel (i.e. people working the sampling) may encounter a wide range of hazards. For example:

- Access to the sampling stations may involve dangerous landscape
- The water to be sampled may be highly contaminated with various pollutants
- The possibility of slipping and injury while wading in streams to takewater samples, etc.

Thus, while leaving for field work to take water samples one should have and obey the following safety practices:

- Consistent use of suitable protective clothing such as rubber gloves to protect against contaminants.
- Training on the awareness of potential hazards and how to deal with them such as on water safety and first-aid.
- Having a first aid kit carried at all times

5.2.3.3. Hydrological Measurements

During water quality sampling hydrological measurements should be taken since they are essential for the interpretation of water quality data. This is because variations in hydrological conditions have important effects on water quality.

Hydrological factors such as discharge (i.e. the volume of water passing through a cross section of river in a unit time, m3/second), the velocity of water flow (m/second), turbulence, water depth, rainfall, wind, erosion, etc are some of the factors that need to be recorded during water sampling.

5.2.3.4. Types of Samples taken from Surface Waters

Two different types of samples can be taken from rivers, lakes and similar surface waters. These are Grab samples and Composite samples. Grab samples are the simplest type taken at a selected site, time and depth. These are also known as "spot" or "snap" samples. Composite samples, also known as integrated samples, are made of several different parts of samples. The following are examples of composite samples:

- Depth-integrated sample: combining samples taken at various depths
- Area-integrated sample: combining samples taken at various sites
- Time-integrated sample: combining samples taken at different times

The type of composite sample to be taken is determined by the objective of sampling. Generally, in water quality sampling programs, standard guidelines (e.g. Bartram and Balance, 1996) should be followed in collecting samples for physio-chemical and biological parameters

Chapter Review Questions

Answer the following questions properly. Refer to the appropriate sections to confirm your answers

1. What is water quality?

2. What are the purposes of measuring water quality?

3. What are factors that affect water quality?

4. List down the various physico-chemical parameters used to measure water quality.

5. Explain how each of the various physico-chemical parameters can be used to measure water quality.

6. What is Biochemical oxygen demand (BOD)? How does it differ from the chemical oxygen demand (COD)?

7. What is the difference between water transparency and turbidity? How do we measure each?

8. Why is pH important in measuring water quality?

9. What are examples of biological parameters we can use to measure water quality?

10. What does Bacteriological analysis help in water quality measurement? Give examples.

11. How does chlorophyll a measurement help in assessing water quality?

12. What are the benthic macroinvertebrates? How are they used in water quality assessment?

13. What are biological indices or scores in water quality assessments? Give examples.

14. What are the basic elements of a field checklist of well-planned water sampling program should include?

15. What is field safety during water sampling? Give examples

16. What are the various hydrological parameters that should be recorded or measured in water quality assessment?

Chapter 6: Aquatic Resources

6.1 Fish and Fisheries

Fishery (fisheries) is a business or an activity of fishing. It comes in two forms namely capture fishery and aquaculture. Capture fishery is the practice of catching fish from natural water bodies using various techniques for commercial or recreational purpose. Aquaculture is, however, the growing or farming of fish (or other beneficial aquatic organisms) in the natural or artificial water bodies mainly for food or commercial purpose.

The term fish is often used to refer to the aquatic vertebrates with fins as appendages and gills as respiratory structures. These are specifically known as finfish. In fishery the term fish is also used to include aquatic invertebrates such as mollusks (e.g. squid and oyster) and crustaceans (e.g. lobster and crab) that are consumed by humans for protein supply. These are specifically known as shellfish (See Fig 7.1 below).

Fig 7.1 (a) Squid (mollusk) (b) Lobster (crustacean) (c) Crab (crustacean)

Shellfish are almost entirely marine forms whereas finfish inhabit both the freshwater and marine habitats. The taxonomic hierarchy of finfish can be represented as shown below:

- Kingdom: Animalia
- Phylum: Chordata
- Subphylum: Vertebrata
    - Fish: there are six classes of fish
        - Class: Ostracoderms
        - Class: Cyclostomata
        - Class: Placodermi
        - Class: Acanthodi
        - Class: Chondrichthyes (cartilaginous fish)
        - Class: Osteichthyes (bony fish)

1. The jawless (agnathan) fish

These are primitive fishes that lack jaws and are thus also known as agnathan fish. They lack the paired fins and have notochord instead of vertebral column. They are largely extinct (e.g. ostracoderms) and some are extant (cyclostomes). Cyclostomes have suctorial circular or round mouth and include two living groups: Lampreys and Hagfishes. The Lampreys are blood sucking (parasitic, usually on other fish), both marine and freshwater forms. The hagfishes are scavengers usually inhabiting marine habitats.

Ostracoderms

They are small, jawless creatures collectively called ostracodrms (ostrakon,shell:+derm,-skin) which belong to the agnatha division of the vertebrates. These earliest jawless fishes lacked pairedfins that later fishes found so important for stability. This class contains the following group of fishes.

Order- Heterostracans (Pteraspida): - Is one group of the earliest known ostracoderms. They had a wide and terror region covered by a carapace. A heavy exoskeleton is present in many early craniate. The plates and scales are formed by a combination of more super ficial denticles and under lying bone. The denticles are like teeth and are composed of the hard tissue, dentine. The lateral line sense organs lay in pits opening by pores between the ridges of dentine.

There are no movable paired fins.The mouth was partly surrounded by long plates. In some of the later heterostracans the mouth was a tube at the very front end. These animals mostly had paired eyes and also a median pineal eye. They had paired nasal sacs. There were only two semicircular canals.

Osteostraci(Cephalaspidiforms): Coexiting with the heterostracans throughout much of the Devonian period were the osteostracans(osteo,bone; ostracon, shell).These are fossil agnathas that show even more similarity to the modern cyclostomes than the heterostracans. The osteostracans improved the efficiency of their benthic life by evolving paired pectoral fins that increased the control of swimming. This ensured well-directed forward movement. The jawless mouth is toothless. Other distinctive features included a sensory lateral line system, paired eyes with complex eye muscle patterns and inner ear with only two semicircular canals. An upturned tail was heterocercal, covered with heavy bony scales.

This class is extinct but had the following characteristics:

- Small fish-like animals(only few centimeters long)
- Bottom dwellers, poor swimmers
- Rudimentary fins and bony armor
- No lower jaw
- No teeth
- Filter feeders or deposit feeders
- Marine

Cyclostomes (Living agnathans)(lampreys and hagfishes)

The class cyclostomata derived its name by having around or circular mouth and include two living groups: Lampreys and Hagfishes. The Lampreys are blood sucking (parasitic, usually on other fish), both marine and freshwater forms. The hagfishes are scavengers usually inhabiting marine habitats.

The class is characterized by the following features:

- Eel- like in structure
- They have rows of horny teeth that move in circular
- The mouth cannot close and always open such that water constantly cycles through it.
- They are Prey (parasitize on fishes)
- Lack exoskeleton/scales
- Notochord persists in adults

The Cyclostomes are very unique among vertebrates because of their semi-parasitic nature. The lampreys with the exception of some small fresh-water forms attach themselves to other fishes using their sartorial mouth and then rasp off the flesh by means of the horny teeth carried by the highly-developed tongue.

The class Cyclostomata consists of two orders:

1. **Order Petromyzontia (or Hyperoartii)**
2. **Order Myxinoidea (or Hyperotreti).**

1. Order: Petromyzontia(orHyperoartii).e.g.lampreys-/Petromyzonmarinus/.

The Petromyzontes are characterized by:

- Soft body without scales
- Pineal (cone-like) eye
- Endo skeleton made of cartilage and notochord
- Seven gill pouches open directly to exterior
- Circular sucking mouth used in parasitizing other fishes
- Lack paired fins but have finray
- Single dorsal nasal open in gontopofthe head
- Cartilaginous braincase
- Ammocoetes larva which metamorphoses to adult

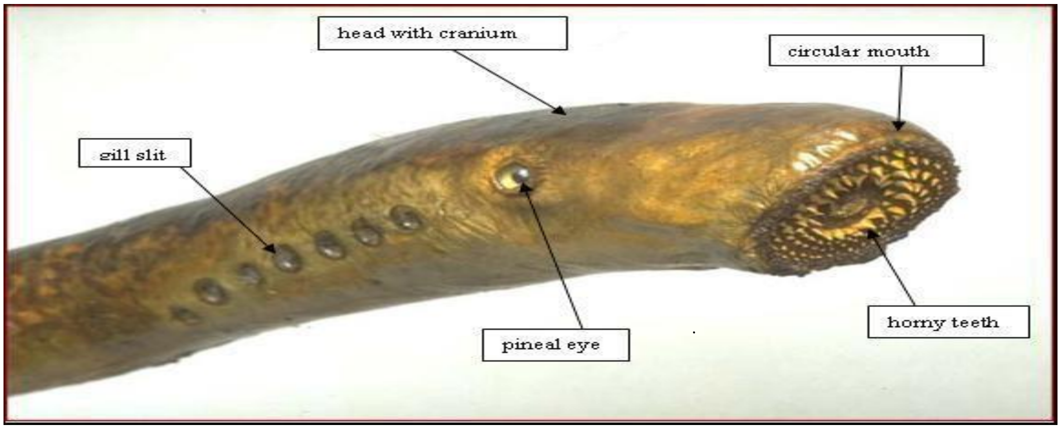


Figure6.3A cyclostome-sealamprey

Order: Myxinoidea(Hyperotreti)

The hagfishes are characterized by:

- ⇨ Circular mouth fitted with rasping tongue surrounded by short tentacle.
- ⇨ Gill pouches joined to a common external opening one it her side
- ⇨ Gasal opening at the tip of the snout rather than on top of the head as in the lampreys
- ⇨ Exclusively marine
- ⇨ Elongate(eel-like)body
- ⇨ Scale less body
- ⇨ Many mucous glands present for anti-predator defense
- ⇨ Unsupported fin ra

Hagfish

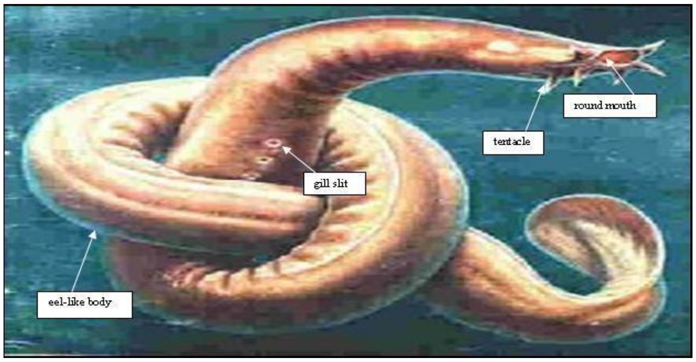


Fig.6.4 A cyclostomes Hagfishes

2. The Jawed vertebrates (Gnathostomata) Fish.

This includes the rest of the four fish classes (Placodermi, Acanthodi, Chondrichthyes and Osteichthyes). Placodermi and Acanthodi are extinct whereas chondrichthyes and osteichthyes are extant groups. These are fish with jaws and are thus also known as gnathostomatan fish. In contrast to the agnathan fish, these possess paired fins. Fishes of the extinct class Placodermi were the first vertebrates to develop jaws and paired fins. A branch of Placodermi probably gave rise to the two main modern classes of fish: the cartilaginous and bony fish.

2.1 Class Placodermi

Class Placodermi includes the earliest gnathostomes except for the acanthodians.They were mostly bottom living animals, dorso ventrally flattened and somewhat like modern rays. Many lived on invertebrate or by shoveling mud, like theiragnathan ancestors. Most lived in the sea, but some in freshwater.

There were paired pectoral and pelvic fins and often large pectoral spines attached to the trunk plate. The male shad pelvic claspers and reproduction was presumably like that of sharks. This feature is one of there as on s for considering that the placoderms were related to the ancestors of the chondrichthyes.

2.1.1 Characteristics of members class Placodermi

- Appear in the Early Silurian and extinct by end of the Devonian
- Predatory

- The sister taxon to all other jawed vertebrates(Eugnathostomata)
- Unique jaw musculature with the muscle's median to the palate quadrates (the upper jaw elements).
- Upper jaws were attached tightly to the craniumor head shield, which limited the mobility of the jaws
- No teeth that resemble those of other jawed vertebrates
- Only some individuals with in a species had pelvic appendages, which in dicate they were male and that the species had internal fertilization
- The head region was covered with thick dermal bone.
- Someformshadamoveablejointbetweentheplateswheretheneckwouldbe, whichallowedthejawstobe openedverywide.

2.2 ClassAcanthodians

The acanthodians, found in freshwater deposits extending from the Ordovician tothe Permian butchie fly in the Devonian, are the oldest known gnathostomes.They weresmall fishes with a fusiform body,heterocercal tail and oneor two dorsal fins. The lateral fins consistedofaseriesofpairs,oftenasmanyasseveninall,downthesidesofthebody. Thefinswereall supportedbythelargespines.

2.2.1 Characteristics ofAcanthodians

Thesister taxontotheOsteichthyes

- E a r l i e s t jawedfishesinthefossilrecorddatingfrom theEarlySilurian,but disappearedbytheEarlyPermian.
- Hadstoutspinesanterior tothedorsal,anal,andmanypairedfins
- Teethlackedenamel
- Few enlarged scales, though some lacked scales.
- Three semicircularcanals
- Craniumcomposedofcartilage

2.3. The Cartilaginous Fish

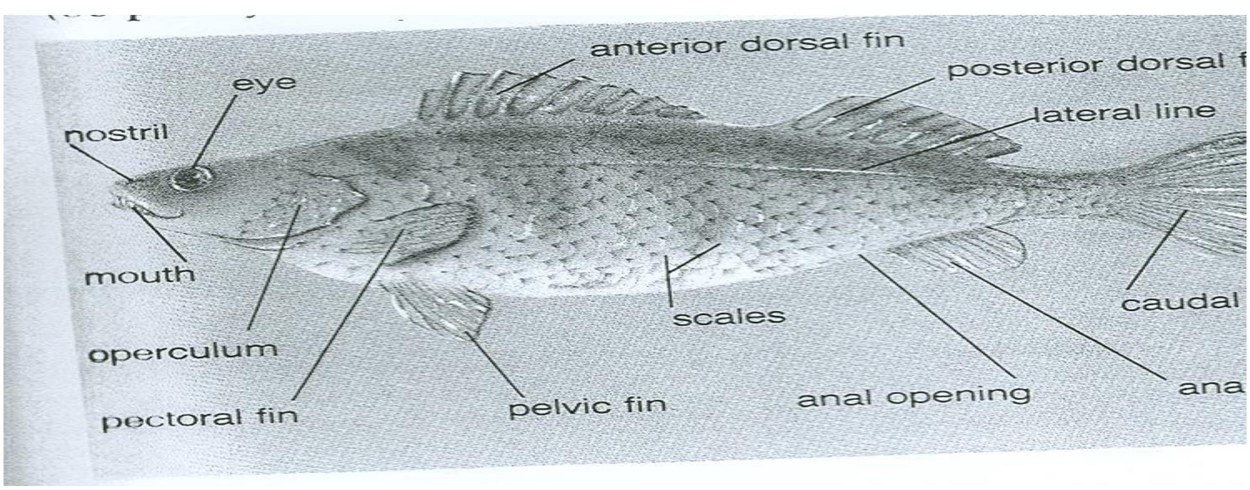
The cartilaginous fishes include 2 major subgroups namely theelasmobranches (such as sharks, rays, skates) and the holocephalans (such as chimaeras or ratfish). The cartilaginous fish are distinguished from the bony fish by their cartilage endoskeleton, lack of swim bladders, lack of a gill covering (operculum) and possession of teeth-like placoid scales. The cartilaginous fish have a rough or a sand paper quality as a result of their teeth-like placoid scales. They are almost exclusively marine in distribution.

2.4. The Bony Fish

Bony fishes are distinguished from other living fishes by their possession of bony skeletons and a swim bladder which functions as a float or, in a few fishes, as a lung. They also possess a bony gill cover known as operculum.The bony fishes are divided into two major subgroups: sarcopterygian and actinopterygian bony fishes. The Sarcopterygian bony fishes include the fleshy finned fish with a central bone supporting the fins. It is further subdivided into two subgroups: Dipnoi (Lungfishes) and Crossopterygii (e.g. Coelacanth).

The dipnoi (lungfish) can breathe using lung for a brief period of time. Thelungfish are mainly freshwater forms in the areas they occur. Examples include Lepidosiren (American lungfish), Protopterus (African lungfish) and Neoceratodus (Australian lung fish). The coelacanths, one group of crossopterygians, are mainly marine deep-sea forms. Latimeriachalmulae is the living fossil (i.e. the only living form) of coelacanth that occurs in Africa in Comoro Archipelago.

Actinopterygian bony fishes are ray finned fish in which a fin consists of a skin supported by horny rays. The paired fins are closely located as opposed to that of the sarcopterygians. They are the most highly successful and diverse of all the fishes and include over 95% of all living fish species predominating both in fresh and marine waters. They represent an advanced adaptation of the bony fishes to strictly aquatic conditions.



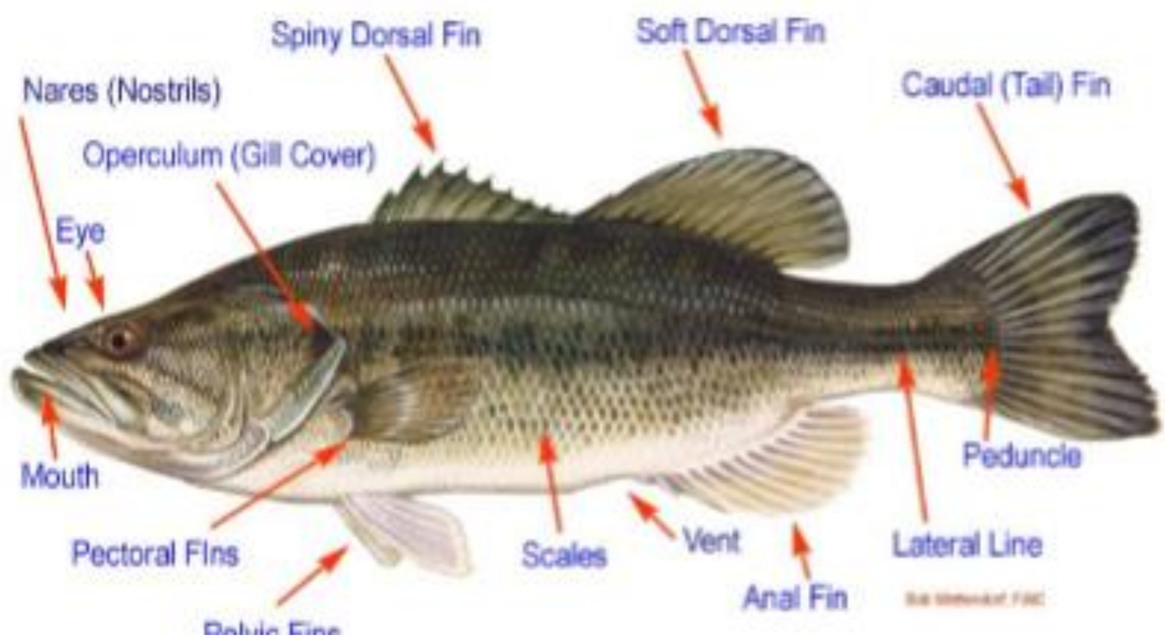


Fig. a. External anatomy of a bony fish, Yellow perch and Fig. External anatomy of a typical actinopterygian bony fish showing the various types of fins. Actinopterigian bony fishes are further subdivided into three groups: Chondrostei, Holostei (Neopterygii) and Teleostei. Chondrostei and Holostei have soft rayed fins that are supported by cartilaginous or soft rays; whereas teleostei have spiny rayed fins that are supported by bony (strong) spines. Examples of Chondrostei include Sturgeons, Bichirs, Paddlefishes and Spoonfishes. Holostei (Neopterygii) includes Bowfin, Garpikes, Gars, and Garfishes. Teleostei are the most advanced and the most numerous groups of actinopterygian fishes comprising about 23, 000 species out of the 24, 000 fish species. These are fish that are important as food and thus important in fishery. The following are the representative orders of teleosts:

- Anguilliformes (Anguillids) e.g. Eel (snake like appearance)
- Clupeiformes (Clupeids) e.g. Herring and Anchovies
- Salmoniformes (Salmonids) e.g. Salmon, Trout, Whitefishes, Pikes and Grayling
- Cypriniformes (Cyprinids/Ostariophysi)- Minnows, Carps, Catfishes
- Perciformes e.g. Perches, Wrasses, Dolphins, Hake, Mackerel, Tuna

6.2. The Ethiopian Fish and Fisheries

6.2.1. The Classification of Ethiopian Fish

Some of the fishes found in Ethiopian lakes and rivers are given by Appendix-4. The Ethiopian fish fauna are the bony fishes and freshwater forms, the majority of them belonging to teleosts. The

Ethiopian fish fauna consists of 153 indigenous and 10 exotic species. It is important to bear in mind, however, that the diversity and abundance of Ethiopian fish fauna is not complete and further works are still underway.

The Ethiopian indigenous freshwater fauna is a mixture of three different forms: Nilo-sudanic forms, East African high land forms and Endemic forms. The Nilo-Sudanic forms are those fishes related to West African fishes and include genera such as Alestes, Bagrus, Citharinus, Hydrocynus, Hyperopisus, Labeo, Mormyrus etc. The similarity is assumed due to past connections of the Nile to Central and West African river systems. These are the dominant forms in terms of diversity and are represented by a large number of species found in the Omo-Gibe, Baro-Akobo, Tekeze and Abay drainage basins but particularly predominate the Nile basin (Baro-Akobo, Tekeze and Abay). However, some elements of these forms also occur in the Southern Rift Valley Lakes (Lakes Abaya and Chamo), and the Shebelle-Ghenale basins. However, Nilotic fishes are almost entirely absent from the Awash and northern rift
valley lakes

The East African highland forms are those related to fishes of eastern and southern Africa and include genera such as Labeobarbus, Clarias, Garra, Oreochromis, and Varicorhinus. These are found in the northern Rift Valleylakes (e.g. Lakes Awassa, Ziwai, Langano), the highland lakes (e.g. Tana and Hayq), and associated river systems, and the Awash drainage basin.

The Endemic forms are very few comprising of about 38 species and 2 subspecies. Examples include a few genera such as Danakilia, Nemacheilus, and Gara (Lakes Abaya and Chamo), Barbus (Lakes Tana and Chamo), etc. Exotic fish introduced to Ethiopian water bodies include fish such as carp in Koka and Fincha dams.

The economically important families of Ethiopian fish include the following:

1. Family Cichlidae (Cichlids)

This family is known to include three species of tilapias in Ethiopia. These are Oreochromis niloticus, T.zilli and T. galilaea. O. niloticus is found in most Ethiopian freshwaters and commonly known as Qoroso, St. Peter fish, Chogofe, etc. O. niloticus is the predominant fish in most of the Ethiopian fisheries.

Fig. **6.4** Oreochromis niloticus (Nile tilapia)

Family Centropomidae (Centropomids) Most members are marine and only genus Lates is a freshwater form both in Ethiopia and Africa. L. niloticus (commonly called Nile perch) is the major species of the genus and found in Ethiopian Lakes such as Chamo, Abaya, Gambella lakes and Baro River. L. niloticus is carnivorous on other fish and thus it not good to introduce them into other water bodies than their natural habitats.

Fig.6.5 Latesniloticus (Nile perch)

3. Family Claridae (Clarids)

The common example is Clariasgariepinus (commonly Catfish, “Ambaza”) found in L. Tana, L. Abaya and Awash River. C. gariepinus can be easily recognized by their elongated body and long hair like barbells around their mouth.

Fig.6.6 Clariasgariepinus (Catfish, Ambaza)

4. Family Cyprinidae (Cyprinids)

It includes genera such as Barbus (commonly in Nechasa), Labeo and Carp. Barbus is more common in rivers than in lakes and is much common in L. Tana among the lakes. Three carp species (Common carp, grass carp and silver carp) are introduced species belonging to this family.

Chapter 7. Water Basin Management and Monitoring

7.1. Basic Water Management and Monitoring Programs

Human beings require water for many different uses including agriculture, irrigation, hydropower generation, drinking water supply, navigation, recreation and above all for healthy ecosystems. All these multiple-uses on water demand coordinated action and management to ensure sustainability of the water resource. Water is often considered as finite and economic commodity taking into account of affordability and equity criteria. Particularly fresh water is a finite and vulnerable resource, but essential to sustain life, development and the environment. Water management and development should be based on a participatory approach, involving users, planners, policy makers and all other stakeholders and users at all levels. Such management approach is known as Integrated

Water Resources Management (IWRM).

IWRM is a comprehensive, participatory planning and implementation tool which promotes the coordination for managing and developing water resources in a way that: Balances social and economic needs, and

Ensures the protection and sustainability of ecosystems for future generations.

Specifically speaking, IWRM approaches involve applying knowledge from various disciplines as well as the insights from diverse stakeholders to devise and implement efficient, equitable and sustainable solutions to water and development problems. This approach is very important especially in the management of transboundary water resources.

7.2. The Nile Basin Initiative (NBI)

The Nile River is the longest river in the world and it has been providing life to the vast Nile basin for hundreds of thousands of years. Two of its major tributaries are the White Nile and the Blue Nile (Abay) Rivers. The major source of White Nile is Lake Victoria in east central Africa and the source of the Blue Nile is Lake Tana in Ethiopian high lands. The White Nile flows generally north through Uganda and into Sudan where it confluences with the Blue Nile (Abay) at Khartoum to form the Nile River proper. The Nile River continues to flow northwards into Egypt and ultimately into the Mediterranean Sea. The Nile River basin has an area of more than 3,349,000 km2. Refer to Appendix-5 on a map of the Nile basin. The Nile River is a transboundary river that generally involves ten African countries. Nile basin countries also known as the riparian countries are countries that lie in the catchment of the Nile River. These include Ethiopia, Sudan, Egypt, Kenya, Tanzania, Uganda, Rwanda, DR Congo, Burundi and Eritrea. Some of the countries have only a small part of their area within the basin, whilst others are virtually entirely within the Basin. Moreover, the countries contribute differently to the basin and have different needs for the water and other resources of the basin. The Nile basin within Ethiopia territory contributes about 58 % to the water of the Nile River.

The Nile River Agreements include:

The Nile Water Agreement of 1929 and 1959

The Nile Basin Initiative Agreement of May 14th, 2010

Most of the Nile basin countries have their own policy frameworks that address the use and management of their water resources including the Nile

River. Let us now see some pints on:

The Nile Water Agreement of 1929 and 1959

The Nile Basin Initiative, and

The Nile Basin Initiative Agreement of May 14th, 2010.

1. The Nile Water Agreement of 1929 and 1959

This is a Nile treaty which Britain signed on behalf of its east African colonies with Sudan and Egypt. Some aspects of the treaty are: Any projects that could threaten the volume of water reaching Egypt are forbidden. The agreement gives Egypt the right to inspect the entire length of the Nile.

Egypt has a right to use about 75 % of the water while Sudan has 11 %

and the rest of the countries share 14 %.

The other riparian countries have to first seek permission from Egypt and Sudan before planning for any large scale development projects on the river that would affect the level and flow of the waters.

Egypt has the right to control, reject and veto any projects from any other nations and has the right to undertake any desired projects and developments freely without consents of other riparian countries.

The upstream riparian countries criticize the treaty saying that it grants Egypt the lion's share of the Nile waters ignoring the rest upstream riparian countries which on the other hand are the major contributors to the Nile River. The treaty is often regarded as a colonial treaty that cannot

be accepted in the era of Freedom. 2. The Nile Basin Initiative (NBI) The struggle for fair and equitable utilization of the Nile River continued to be a stance of most of the riparian countries. Accordingly, the Nile Basin Initiative was established by the riparian countries in 1999. NBI is a transitional arrangement established by the Nile Basin States at the meeting of their Council of Ministers held in Dar-es-Salaam, Tanzania, on 22nd February, 1999. NBI:

Is responsible to foster cooperation and sustainable development of the Nile River for the benefit of the inhabitants of the riparian countries.

Seeks to develop the river in a cooperative manner, share substantial socioeconomic benefits, and promote regional peace and security.

The NBI secretariat is based in Entebbe, Uganda and led by the Council of Ministers of Water Affairs of the Nile Basin states (Nile Council of Ministers, or NILE-COM). 3. The New Nile Basin

Framework of 2010 For over a decade, the nine riparian countries and Eritrea as an observer have been negotiating to draft a new treaty on the usage of the Nile waters. All the

countries agreed on the framework agreement apart from a clause which will reduce Egypt and Sudan's right to use more than 85 percent of the water. However, Egypt and Sudan want to maintain the old status quo of them using the biggest percentage of the water as stipulated in two colonial agreements they signed with the British in 1929 and 1959.

Ultimately the Nile Basin Initiative Agreement was signed among four Nile basin countries (Ethiopia, Rwanda, Tanzania, and Uganda) who signed the Agreement on the “Nile River Basin Cooperative Framework” in Uganda on 14th May, 2010. Burundi, Democratic Republic of Congo (DR Congo) and Kenya are expected to join the agreement sooner. The Cooperative

Framework stipulates fair and equitable utilization of the Nile River basin and will remain open for one year to allow Egypt and Sudan join the rest of the countries.

Some of the reasons for reaching the Nile Basin Initiative Agreement on the

“Nile River Basin Cooperative Framework” in May, 2010 include:

The old colonial treaty signed among Britain, Egypt and Sudan was not fair and does not entail equitable utilization of the Nile River Basin.

The riparian countries are now independent states and thus have equal

rights as Egypt to use the Nile waters.

The upstream countries are in dire need of using the water to generate hydropower and irrigation following persistent drought which has hit many of the countries leaving millions of their citizens on the verge of starvation. According to the framework agreement the Nile Basin Initiative will be transformed into the Nile Basin Commission which will coordinate the equitable usage of the water.

7.3. The Water Framework Directive

The Water Framework Directive is a European Union water legislation which commits European Union member states to achieve good qualitative and quantitative status of all water bodies by 2015. The Directive was made on 23 October 2000 and came into force 22 December 2000. Currently is an active legislation.

The following are some of the important points you need to note about the Directive:

The Directive establishes a framework for the European Community action in the field of water policy.

It is a framework in the sense that it prescribes steps to reach the common goal rather than adopting the more traditional limit value approach.

The directive defines 'surface water status' as the general expression of the status of a body of surface water, determined by the poorer of its ecological status and its chemical status.

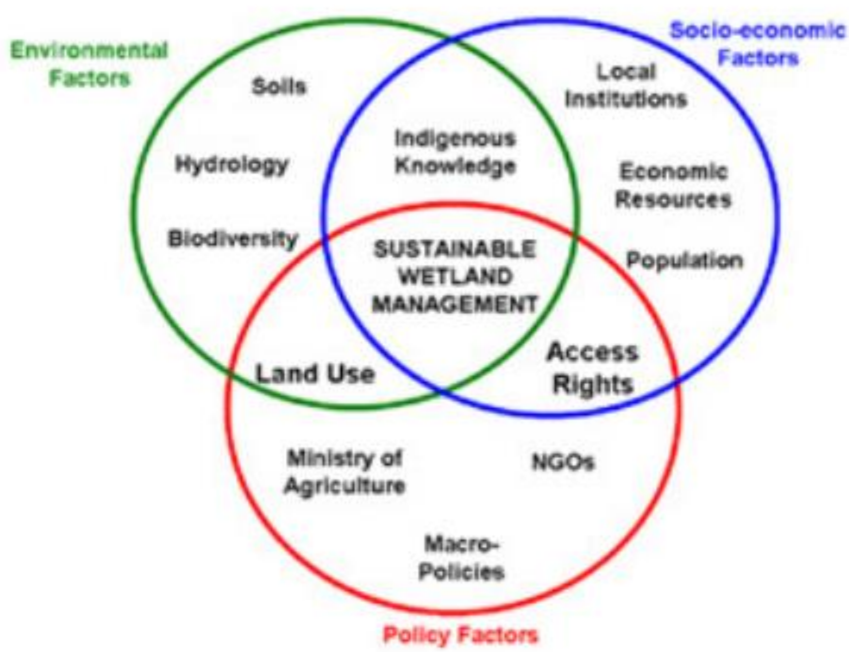
Thus, to achieve 'good surface water status' both the ecological status and the chemical status of a surface water body need to be at least 'good'. Ecological status refers to the quality of the structure and functioning of aquatic ecosystems of the surface waters.

Water is an important facet of all life and the water framework directive sets standards which ensure the safe access of this resource.

The Directive aims "River Basin Management"

7.4. Convention on Wetlands Management

Wetland have integrated approaches and multifunctional, hence it deserve to use and manage our wetlands, for sustainable economy and biodiversity under treatment.



For instance, sustainable management of wetlands requires maintaining some of the natural characteristics of wetlands while also allowing partial conversion to allow activities which can meet the economic needs of communities. A balance has to be struck between the environmental functioning of wetlands and their use for livelihood purposes. Usually sustainable management of wetlands involves minimal conversion of the wetland and limited degradation of the catchment. In the following sections we will see about the wetlands management in Ethiopia and at international level.

1. Wetlands Management in Ethiopia

Generally in Ethiopia, wetland management has been given little attention until a nongovernmental organization namely Ethio Wetlands and Natural Resources Association **(EWNRA)** initiated research in southwest Ethiopia, Illubabor zone, Oromia regional state, for the sustainable management of wetlands.

2. Wetlands Management at International Level

Ramsar Convention on Wetlands Management is an international intergovernmental treaty adopted on 2 February 1971 in the Iranian city of Ramsar to address global concerns regarding wetland loss and degradation. It is the first of the modern global intergovernmental treaties on the conservation and sustainable use of natural resources. The Convention entered into force in
1975 and as of December 2006 has 153 Contracting Parties, or member States, in all parts of the world. Ethiopia is not among the Ramsar Convention Member State.

The Convention was primarily on wetlands of international importance, especially as Waterfowl (water birds) habitat. Over the years, however, the Convention has broadened its scope of implementation to cover **all aspects** of wetland conservation and wise use, recognizing wetlands as ecosystems that are extremely important for biodiversity conservation and for the well-being of human communities.

The primary purposes of the treaty are to list wetlands of international importance and to promote their wise use, with the ultimate goal of preserving the world's wetlands. Methods include restricting access to the majority portion of wetland areas, as well as educating the public to combat the misconception that wetlands are wastelands.

Principles of Wetland Restoration

To help build on the lessons of restoration projects and promote effective restoration, the Office of Wetlands, Oceans and Watersheds assembled the following list of principles that have been critical to the success of a wide range of aquatic resource restoration projects. These principles apply to different stages in the life of a restoration project - from early planning to post-implementation monitoring - and are offered here for use by a wide variety of people and organizations, ranging from Federal, State, Tribal and local agencies to outdoor recreation or conservation groups, corporations, landowners and citizens' groups.

These principles focus on scientific and technical issues, but as in all environmental management activities, the importance of community perspectives and values should not be overlooked. The presence or absence of public support for a restoration project can be the difference between positive results and failure. Coordination with the people and organizations that may be affected by the project can help build the support needed to get the project moving and ensure long-term protection of the restored area. In addition, partnership with stakeholders can also add useful resources, ranging from money and technical expertise to volunteer help with implementation and monitoring.

Restoration Guiding Principles

Some of these include

- Preserve and protect aquatic resources
- Restore ecological integrity
- Restore natural structure
- Restore natural function
- Work within the watershed/landscape context
- Understand the potential of the watershed
- Address ongoing causes of degradation
- Develop clear, achievable and measurable goals
- Focus on feasibility
- Use reference sites
- Anticipate future changes
- Involve a multi-disciplinary team
- Design for self-sustainability
- Use passive restoration, when appropriate

- Restore native species, avoid non-native species
- Use natural fixes and bioengineering
- Monitor and adapt where changes are necessary

1. **Preserve and protect aquatic resources.** Existing, relatively intact ecosystems are the keystone for conserving biodiversity, and provide the biota and other natural materials needed for the recovery of impaired systems. Thus, restoration does not replace the need to protect aquatic resources in the first place. Rather, restoration is a complementary activity that, when combined with protection and preservation, can help achieve overall improvements in a greater percentage of the Nation's waters. Even with water bodies for which restoration is planned, the first objective should be to prevent further degradation.
2. **Restore ecological integrity.** Restoration should re-establish insofar as possible the ecological integrity of degraded aquatic ecosystems. Ecological integrity refers to the condition of an ecosystem -- particularly the structure, composition and natural processes of its biotic communities and physical environment.

    - An ecosystem with integrity is a resilient and self-sustaining natural system able to accommodate stress and change. Its key ecosystem processes, such as nutrient cycles, succession, water levels and flow patterns, and the dynamics of sediment erosion and deposition, are functioning properly within the natural range of variability.
    - Biologically, its plant and animal communities are good examples of the native communities and diversity found in the region.
    - Structurally, physical features such as the dimensions of its stream channels are dynamically stable.

Restoration strives for the greatest progress toward ecological integrity achievable within the current limits of the watershed, by using designs that favor the natural processes and communities that have sustained native ecosystems through time.

3. **Restore natural structure.** Many aquatic resources in need of restoration have problems that originated with alteration of channel form or other physical characteristics, which in turn may have led to habitat degradation, changes in flow regimes and siltation. Stream channelization, ditching in wetlands, disconnection from adjacent ecosystems and shoreline modifications are examples of structural alterations that may need to be addressed in a restoration project. In such

cases, restoring the original site physical attributes is essential to the success of other aspects of the project, such as improving water quality and bringing back native biota.

4. **Restore natural function.** Structure and function are closely linked in river corridors, lakes, wetlands, estuaries and other aquatic resources. Reestablishing the appropriate natural structure can bring back beneficial functions. For example, restoring the bottom elevation in a wetland can be critical for reestablishing the hydrological regime, natural disturbance cycles and nutrient fluxes. In order to maximize the benefits of the restoration project, it is essential to identify what functions should be present and make missing or impaired functions priorities in the restoration. Verifying whether desired functions have been re-established can be a good way to determine whether the restoration project has succeeded.
5. **Work within the watershed and broader landscape context.** Restoration requires a design based on the entire watershed, not just the part of the water body that may be the most degraded site. Activities throughout the watershed can have adverse effects on the aquatic resource that is being restored. A localized restoration project may not be able to change what goes on in the whole watershed, but it can be designed to better accommodate watershed effects. New and future urban development may, for example, increase runoff volumes, stream down cutting and bank erosion, and pollutant loading. By considering the watershed context in this case, restoration planners may be able to design a project for the desired benefits of restoration, while also withstanding or even helping to remediate the effects of adjacent land uses on runoff and nonpoint pollution.
6. **Understand the natural potential of the watershed.** Establishing restoration goals for a water body requires knowledge of the historical range of conditions that existed on the site prior to degradation and what future conditions might be. This information can then be used in determining appropriate goals for the restoration project. In some cases, the extent and magnitude of changes in the watershed may constrain the ecological potential of the site. Accordingly, restoration planning should take into account any irreversible changes in the watershed that may affect the system being restored, and focus on restoring its remaining natural potential.
7. **Address ongoing causes of degradation.** Restoration efforts are likely to fail if the sources of degradation persist. Therefore, it is essential to identify the causes of degradation and eliminate or remediate ongoing stresses wherever possible. While degradation can be caused by one direct impact, such as the filling of a wetland, much degradation is caused by the cumulative effect of numerous, indirect impacts, such as changes in surface flow caused by gradual increases in the

amount of impervious surfaces in the watershed. In identifying the sources of degradation, it is important to look at upstream and up-slope activities as well as at direct impacts on the immediate project site. In some situations, it may also be necessary to consider downstream modifications such as dams and channelization.

8. **Develop clear, achievable and measurable goals.** Restoration may not succeed without good goals. Goals direct implementation and provide the standards for measuring success. Simple conceptual models are a useful starting point to define the problems, identify the type of solutions needed and develop a strategy and goals. Restoration teams should evaluate different alternatives to assess which can best accomplish project goals. The chosen goals should be achievable ecologically, given the natural potential of the area, and socioeconomically, given the available resources and the extent of community support for the project. Also, all parties affected by the restoration should understand each project goal clearly to avoid subsequent misunderstandings.
9. **Focus on feasibility.** Particularly in the planning stage, it is critical to focus on whether the proposed restoration activity is feasible, taking into account scientific, financial, social and other considerations. Remember that solid community support for a project is needed to ensure its long-term viability. Ecological feasibility is also critical. For example, a wetlands restoration project is not likely to succeed if the hydrological regime that existed prior to degradation cannot be reestablished.
10. **Use a reference site.** Reference sites are areas that are comparable in structure and function to the proposed restoration site before it was degraded. As such, reference sites may be used as models for restoration projects, as well as a yardstick for measuring the progress of the project. While it is possible to use historic information on sites that have been altered or destroyed, historic conditions may be unknown and it may be most useful to identify an existing, relatively healthy, similar site as a guide for your project. Remember, however, that each restoration project will present a unique set of circumstances, and no two aquatic systems are truly identical. Therefore, it is important to tailor your project to the given situation and account for any differences between the reference site and the area being restored.
11. **Anticipate future changes.** The environment and our communities are both dynamic. Although it is impossible to plan for the future precisely, many foreseeable ecological and societal changes can and should be factored into restoration design. For example, in repairing a stream channel, it is important to take into account potential changes in runoff resulting from projected increases in upstream impervious surface area due to development. In addition to potential

impacts from changes in watershed land use, natural changes such as plant community succession can also influence restoration. For instance, long-term, post-project monitoring should take successional processes such as forest regrowth in a stream corridor into account when evaluating the outcome of the restoration project.

12. **Involve the skills and insights of a multi-disciplinary team.** Restoration can be a complex undertaking that integrates a wide range of disciplines including ecology, aquatic biology, hydrology and hydraulics, geomorphology, engineering, planning, communications and social science. It is important that, to the extent that resources allow, the planning and implementation of a restoration project involve people with experience in the disciplines needed for the particular project. Universities, government agencies and private organizations may be able to provide useful information and expertise to help ensure that restoration projects are based on well-balanced and thorough plans. With more complex restoration projects, effective leadership will also be needed to bring the various disciplines, viewpoints and styles together as a functional team.
13. **Design for self-sustainability**. Perhaps the best way to ensure the long-term viability of a restored area is to minimize the need for continuous maintenance of the site, such as supplying artificial sources of water, vegetation management, or frequent repairing of damage done by high water events. High maintenance approaches not only add costs to the restoration project, but also make its long-term success dependent upon human and financial resources that may not always be available. In addition to limiting the need for maintenance, designing for self-sustainability also involves favoring ecological integrity, as an ecosystem in good condition is more likely to have the ability to adapt to changes.
14. **Use passive restoration, when appropriate.** Before actively altering a restoration site, determine whether passive restoration (i.e., simply reducing or eliminating the sources of degradation and allowing recovery time) will be enough to allow the site to naturally regenerate. For some rivers and streams, passive restoration can re-establish stable channels and floodplains, regrow riparian vegetation and improve in-stream habitats without a specific restoration project. With wetlands that have been drained or otherwise had their natural hydrology altered, restoring the original hydrological regime may be enough to let time reestablish the native plant community, with its associated habitat value. It is important to note that, while passive restoration relies on natural processes, it is still necessary to analyze the site's recovery needs and determine whether time and natural processes can meet them.

15. **Restore native species and avoid non-native species.** American natural areas are experiencing significant problems with invasive, non-native (exotic) species, to the great detriment of our native ecosystems and the benefits we've long enjoyed from them. Many invasive species outcompete natives because they are expert colonizers of disturbed areas and lack natural controls. The temporary disturbance present during restoration projects invites colonization by invasive species which, once established, can undermine restoration efforts and lead to further spread of these harmful species. Invasive, non-native species should not be used in a restoration project, and special attention should be given to avoiding the unintentional introduction of such species at the restoration site when the site is most vulnerable to invasion. In some cases, removal of non-native species may be the primary goal of the restoration project.
16. **Use natural fixes and bioengineering techniques, where possible.** Bioengineering is a method of construction combining live plants with dead plants or inorganic materials, to produce living, functioning systems to prevent erosion, control sediment and other pollutants and provide habitat. Bioengineering techniques can often be successful for erosion control and bank stabilization, flood mitigation and even water treatment. Specific projects can range from the creation of wetland systems for the treatment of storm water, to the restoration of vegetation on river banks to enhance natural decontamination of runoff before it enters the river.
17. **Monitor and adapt where changes are necessary.** Every combination of watershed characteristics, sources of stress, and restoration techniques is unique and, therefore, restoration efforts may not proceed exactly as planned. Adapting a project to at least some change or new information should be considered normal. Monitoring before and during the project is crucial for finding out whether goals are being achieved. If they are not, "mid-course" adjustments in the project should be undertaken. Post-project monitoring will help determine whether additional actions or adjustments are needed and can provide useful information for future restoration efforts. This process of monitoring and adjustment is known as adaptive management. Monitoring plans should be feasible in terms of costs and technology, and should always provide information relevant to meeting the project goals.