Course: Environmental Analysis and Protection

Chapter 01: Fundamental Concepts.

1-Concept of environment:

Any external factor affecting an organism is part of the concept of 'Environment'. It may be another organism or one of the non-living variables (water, soil, climate, light, oxygen, etc.). The environment is a complex system composed of soil, water, air, the living world (animals and plants), as well as all types of interactions among them.

1-1-Environmental degradation:

Environmental degradation is one of the major threats to our planet. It occurs due to multiple damages suffered by the environment, caused by many factors. It can lead to numerous consequences such as species extinction, biodiversity loss, deterioration of air quality, water pollution, soil erosion, and an increase in the greenhouse effect.

1-1-2- Environmental protection:

The protection of the environment consists of conserving the animal and plant species that compose it, as well as preserving the ecological integrity of their natural habitats. This is achieved by taking measures that limit the negative impact of human activities on the environment. Such action is therefore simultaneously scientific (development of knowledge), civic (involving all generations of the community), and political (requiring the enforcement of environmental laws and regulations).

1-2- Concept of ecosystem quality assessment:

The assessment of the ecological quality of ecosystems is implemented in order to establish appropriate measures to combat the massive decline of biodiversity. It is carried out through the estimation of a set of parameters and indices (physico-chemical, organic, or biological, etc.) and their comparison with reference standards, with the aim of determining the degree of pollution (poor ecological quality) or cleanliness (good ecological quality) of environments.

1-3- Concept of environmental analysis:

This refers to an estimation of the quality of a medium (water, soil, atmosphere), in order to evaluate its ecological condition and natural diversity. This can be achieved by:

- Identifying pollutants (pesticides, trace elements, etc.) through quantitative and qualitative analyses carried out in several steps (extraction, derivation, separation of elements, etc.).
- Adapting international conventions and environmental directives organized by specific commissions, in order to implement regulations that protect the environment.

1-3-1- Objectives of environmental analysis:

The objectives of environmental analyses are:

- Evaluation of the state of the environmental system at a given time (monitoring).
- Study of the impact of state organizations or private companies on the environment.
- Assessment of the anthropogenic system's impact on the environmental system.
- Study and planning of measures that can reduce identified hazards and the scheduling of their implementation.

1-3-2- Analyzed matrices:

The sample to be studied may undergo different techniques within the same specific analysis, or techniques applicable to several selective analyses. Environmental monitoring can be carried out in several physical environments (water, air, soil), using chemical, physical, or biological studies, in order to identify any natural anomaly and implement measures to correct it. The environments analyzed can be:

- **Waters**

Various types of water are analyzed to control environmental quality: wastewater, surface water, and groundwater. Water monitoring programs are also undertaken under international conventions for marine waters (Oslo and Paris Commission – OSPAR, 1992; Helsinki – HELCOM, 1974; Barcelona Convention, 1976) or rivers. Rainwater is also analyzed to assess the impact of acid rain and atmospheric fallout (such as lead alkyl compounds) on the environment within international programs.

- **Sediments**

These are particles suspended in water, the atmosphere, or ice, which eventually settle onto surfaces by the force of gravity. The analysis of these sediments is necessary to calculate the pollutant load. Indeed, contaminants (organic and inorganic) are absorbed by these particles in polluted environments.

- **Soils, sludge, and compost**

These media can be the subject of agronomic studies (plant assimilation, soil deficiencies), or environmental risk assessments (pollutant distribution in soils, determination of element or organic compound contents). The fertilizing value of compost can be measured by chemical properties (pH, electrical conductivity, element content, etc.).

- **Biological samples**

These refer to natural species that serve as indicators of pollution, such as: mosses, which accumulate heavy metals in their tissues; lichens, which resist atmospheric pollutants; diatoms (algae), which are sensitive to pollution; and certain fish species that accumulate pollutants from aquatic environments in their tissues, making them good indicators of aquatic ecosystem quality.

- **Atmospheric samples**

Atmospheric emissions are often measured using filters from road tunnels. The excessive use of coal in industry and the economy leads to environmental control responses, as well as numerous analysis programs.

2- Determined parameters:

2-1- Physico-chemical parameters and standards (Aquatic ecosystem case):

2-1-1- Temperature (T):

This is a physical quantity and an important ecological factor for species survival. It plays a key role in the solubility and dissociation of salts and gases (oxygen). Its increase can disrupt the aquatic life of species (thermal pollution). Warm water can accelerate the life and activity of microorganisms and algae, and influence other physico-chemical parameters (pH, conductivity, oxygen content, etc.). Temperature is measured with a thermometer in degrees Celsius (°C). In soils, an increase in temperature can affect the mobility of metals and accelerate bacterial activity

Tab 01. Temperature and water Quality

Temperature (°C)	Water Quality
≤ 20	Normal
20–22	Good
22–25	Average
25–30	Poor
≥ 30	Bad

2-1-2- Hydrogen potential (pH):

This is a chemical measure of hydrogen ion concentrations (H^+) in water (pH = – log [H^+]). Industrial discharges into the soil or runoff water entering aquatic environments may cause variations, which are considered an important indicator of natural pollution.

Acidic pH values (pH < 7) increase the risk of metals being present in a toxic ionic form. In terrestrial environments, this imbalance can lead to soil salinization, a mechanism that contributes to the inhibition of bacterial activity and a slowdown in the decomposition of organic matter.

It is measured using a pH meter and has no unit. Its value ranges from 0 to 14, going from acidic to basic, with neutral pH (pH = 7) in between:

- $[H^+] < [OH^-] \Rightarrow pH > 7$: the water is basic.
- $[H^+] > [OH^-] \Rightarrow pH < 7$: the water is acidic.
- $[H^+] = [OH^-] \Rightarrow pH = 7$: the water is neutral.

Tab 02. pH and water quality

pH Range	Aquatic Environment Quality
pH < 5	Unsuitable for species survival
5 < pH < 6	Tolerable for species
6 < pH < 7.5	Optimal (life and reproduction)
7.5 < pH < 8.5	Optimal for plankton
pH > 8.5	Inability of algae to survive
pH > 9	Inability of species to survive

2-1-3- Electrical conductivity (EC):

This is the ability of a solution to conduct an electric current. It indicates the degree of mineralization of water, whose main salts are: Ca^{2+} (Calcium), Mg^{2+} (Magnesium), Na^+ (Sodium), K^+ (Potassium), etc. The more mineralized the water, the higher its electrical conductivity. Indeed, the anions and cations present in a polluted environment contribute to creating a magnetic field capable of allowing electric current to pass through its components. It is measured using a conductimeter in µS/cm. Aquatic species generally cannot tolerate significant variations in dissolved salts.

Tab 03. Electrical Conductivity and water quality

Conductivity (µS/cm)	Water Quality
50–400	Excellent
400–750	Good
750–1500	Poor
>1500	Excessive mineralization (Pollution)

2-1-4- Dissolved oxygen (Oxygen saturation) (DO):

Oxygen is an essential element for the survival of aquatic species. It comes from the atmosphere or from the photosynthetic activity of algae. Its concentration in aquatic environments varies according to the time of day (temperature) and the depth of the marine environment (lower in deeper waters).

The concentration of dissolved oxygen in water is expressed in mg/L.

- **COD (Chemical oxygen demand):** This is a measure of the organic matter present in water (polluting matter), estimated by the quantity of oxygen required to chemically degrade it (using a specific oxidant).
- **BOD_5 (Biochemical oxygen demand over 5 days):** This represents the amount of oxygen required by aquatic microorganisms during their process of degrading (oxidizing) part of the organic matter present in the environment over a period of 5 days.

The amount of oxygen required in this process reflects the degree of acceleration or decrease in bacterial activity, as well as the level of pollution in the environment.

Tab 04. BOD_5 and water quality

BOD_5 (mg/L O_2)	Water Quality
< 1	Excellent
2	Good
3	Average
5	Moderately polluted
> 10	Polluted water

2-1-5- Water hardness (TH):

This is the sum of the concentrations of metallic cations: Ca^{2+} (Calcium), Mg^{2+} (Magnesium). Their presence can reduce the toxicity of metals, making hardness an indicator of environmental pollution. The total hardness is expressed as: $\mathbf{TH = [Ca^{2+}] + [Mg^{2+}]}$. A low value of water hardness indicates a good living environment for species.

Tab 05. Hardness and water quality

Hardness (mg/L as $CaCO_3$)	Water Quality
0–30	Very soft
31–60	Soft
61–120	Moderately soft
121–180	Hard
> 180	Very hard

2-1-6- Organoleptic parameters of water :

These are factors noticeable during water consumption (color, taste, odor, etc.), and any disturbance in them presents a risk to human health.

a) Turbidity

This indicates the degree of absorption or diffusion of light in an aquatic environment, which depends on the presence or absence of suspended matter in the water, such as clay or silt. Increased turbidity allows microorganisms to attach to suspended particles.

b) Color

Water color changes according to its composition in matter (microorganisms) or metallic elements: for example, the presence of iron gives water a rusty color, while manganese gives it a black color.

c) Taste and Odor

The taste and odor of an aquatic environment change due to the presence of volatile substances such as chlorine (Cl) or sulfur dioxide (SO_2), or organic substances such as esters and alcohols. The change in the taste of drinking water may also result from microbial activity (bacteria).

2-2- Inorganic (geochemical) parameters:

Chemical elements are present in natural ecosystems in various forms (major elements, minor elements, trace elements, bioavailable elements, toxic elements, rare earth elements, trace nutrients, etc.) (Fig. 01). Geochemistry is the discipline that studies the origin, evolution, and distribution of chemical elements in natural environments. Its objective is to assess the chemical processes that govern the composition of rocks, water, and soils, as well as to monitor the cycles of matter and energy that transport chemical components from soils to atmospheric and aquatic environments.

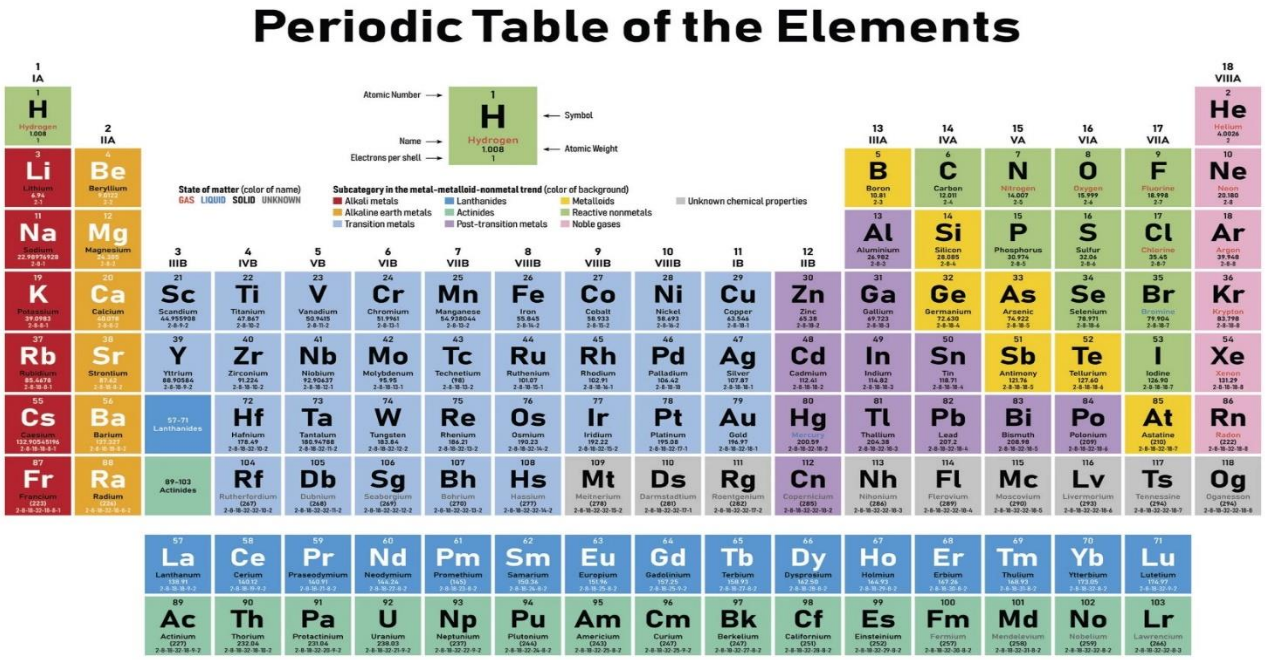

Figure 01. chemical elements in nature

2-2-1- Major Elements:

These are the main chemical elements that make up rocks and minerals. The 12 major elements present in nature account for about 99.4% of all elements. They are essential for plants, but when their concentration exceeds the natural tolerance threshold, they can cause environmental pollution (from agricultural and industrial emissions). The main major elements in natural ecosystems are:

- **Aluminum (Al):**

A toxic element found as an ion (Al^{3+}) in acidic waters. Its presence at concentrations above 0.2 mg/L causes detectable toxicity in consumers.

- **Nitrogen (N):**

Its cycle maintains a critical balance between atmospheric nitrogen fixation (N_2) and denitrification (production of N_2). Nitrate concentrations in groundwater should remain below 1 mg/L.

- **Calcium (Ca):**

Responsible for water hardness, it is the most dominant element in water. Good-quality drinking water contains between 100 and 140 mg/L of calcium.

- **Magnesium (Mg):**

Derived from the dissolution of carbonate formations. Like calcium, it significantly contributes to water hardness, with concentrations rarely exceeding 15 mg/L.

- **Phosphorus (P):**

Originating from the leaching of agricultural areas fertilized with phosphate-based fertilizers, phosphorus plays a key role in algal growth, contributing—when excessive—to the eutrophication of aquatic environments.

- **Potassium (K):**

Comes from the weathering of silicate formations, potassic clays, industrial discharges, and the dissolution of chemical fertilizers. It is present in water at concentrations exceeding 20 mg/L.

2-2-1-1- Major Elements and Plant Metabolism:

Plants absorb nutrients from the soil. Therefore, it is necessary to maintain soil fertility by replenishing its reserves through appropriate mineral inputs, which vary according to the richness of the environment and the specific needs of plants. Annual soil analyses make it possible to determine their content in major and trace elements. This allows for the correction of potential deficiencies by providing the necessary supplements.

On the other hand, the intensified use of chemical fertilizers and phytosanitary products **(Fig. 02)** on plants or soils, aimed at improving annual yields, leads to runoff and infiltration, eventually contaminating soils, surface waters, groundwater, fauna, flora, food chains, and ultimately human health. This excessive mineralization results in the presence and persistence of these elements at concentrations and levels exceeding natural standards, causing a massive degradation of soil fertility. Hence, it is essential to apply crop rotation practices on such agricultural lands.

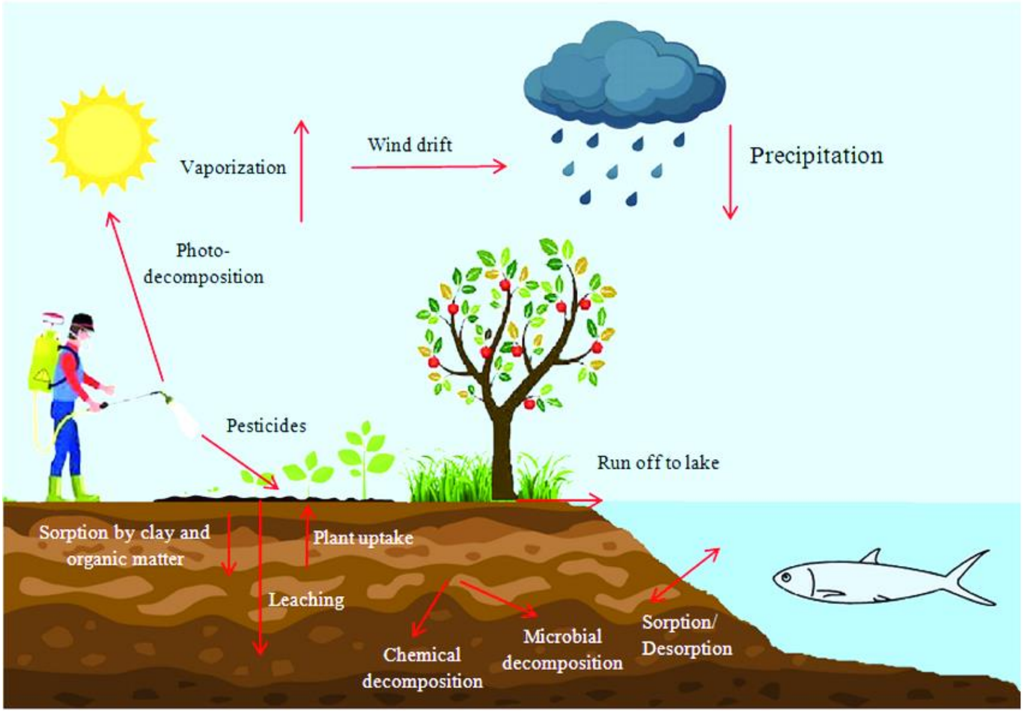

Figure 02. Pesticide cycle in nature

2-2-2- Trace Elements:

Trace elements are toxic to living organisms even at relatively low concentrations. There are about 80 trace elements in nature, representing only about 0.6% of all existing elements. Among metallic trace elements, the following can be cited:

- **Arsenic (As):**

Used in metallurgy (alloys), electronics (semiconductors), paint manufacturing, and glass coloring.

- **Boron (B):**

Used as an antiseptic and in the glass, ceramic, cosmetic, paint, and pesticide industries.

- **Bromine (Br):**

Found in seawater and mineral deposits, it may occur as bromides in polluted areas.

- **Cadmium (Cd):**

Originates from plastics, motor oils, batteries, soldering materials, and natural fertilizers.

- **Chromium (Cr):**

Found in higher concentrations in basic rocks and in trace amounts in silicates. Industrial sources include electroplating, tanning, refining, metallurgy, and dye production.

- **Mercury (Hg):**

Mainly used in metallurgy, medicine, cosmetics, and alchemy. It is highly toxic to humans and the environment.

2-2-2-1- Toxicity of Trace Metallic Elements (TMEs):

Trace metallic elements naturally occur in the form of inert minerals, but they become dangerous once released into the environment through human activities. TMEs are toxic to living organisms (microorganisms, plants, animals, and humans) depending on the dose and level of exposure. They can be transferred from contaminated soils and irrigation water to agricultural and food products, causing various health problems in humans and animals (respiratory diseases, cancers, etc.).

2-2-2-2- Different Analyses of Soil Ecological Quality:

Soil analysis is commonly carried out to assess the potential for sustainable land use, with the goal of conserving resources and managing environmental erosion losses. To perform a complete assessment of soil quality, several structural aspects must be considered:

1. **Physical Analyses:**

These analyses provide information on soil texture (granulometry), structure, water retention capacity, and oxygen circulation in the terrestrial environment.

2. **Physico-chemical Analyses:**

They determine the chemical status of the soil, including pH, moisture, electrical conductivity, total and active $CaCO_3$ content, carbon content, organic matter, and nitrogen levels.

3. **Biological Analyses:**

Biological analysis evaluates the evolution of the soil's organic status. The first indicator is the **C/N ratio** (total carbon to total nitrogen). The ecological study of soil fauna (fungi, bacteria, etc.), along with the estimation of the decomposition rate of degrading matter, provides insight into soil quality.

4. **Soil Geochemical Background:**

This involves studying the chemical composition and concentration of major and trace metallic elements in the soil to determine the quality of the flora and fauna it supports. It consists of:

- The natural geochemical background, resulting from the evolution of parent rocks and natural inputs.
- The anthropogenic background, which reflects the concentration of elements introduced into the environment through human activities (agriculture and industry).

2-3- Organic Parameters:

2-3-1- Definition of Organic Matter:

Organic matter is the material that composes the tissues of living organisms. It is mainly made up of living and dead biomass, undergoing a continuous cycle of decomposition and biosynthesis **(Fig. 03)**. It consists of carbon, hydrogen, oxygen, and small amounts of nitrogen, phosphorus, potassium, sulfur, etc. Organic matter exists in two main forms:

- **Humic Substances (Humus):**

Acidic, hydrophilic substances formed through the biological degradation and chemical oxidation of animal and plant residues (macromolecules). They represent about 30 to 50% of total organic carbon.

- **Non-Humic Substances:**

These include proteins, peptides, amino acids, fats, and small molecules degraded by enzymes secreted by microorganisms.

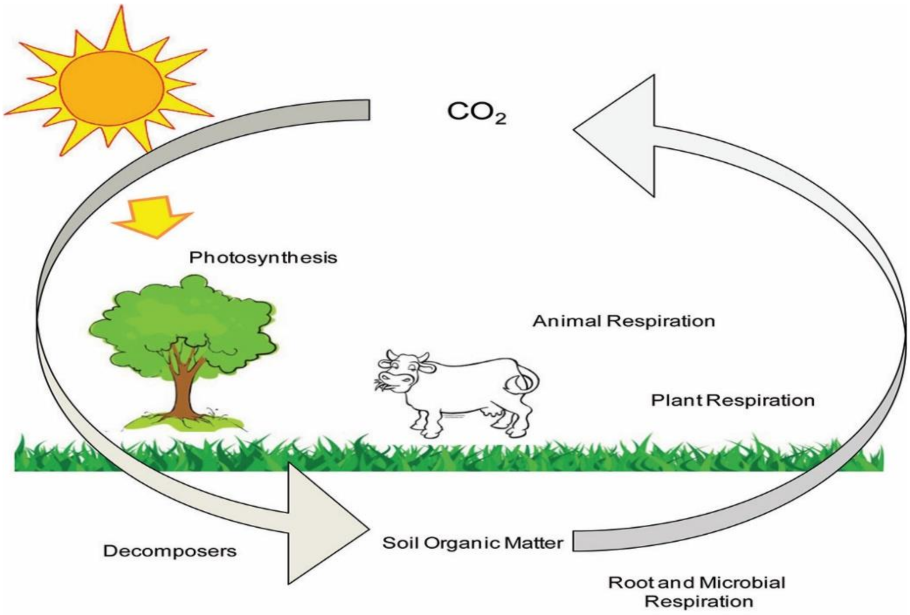

Figure 03. Organic matter cycle in nature

2-3-2- Production of Organic Matter:

The primary function of plants is to produce organic matter through photosynthesis **(Fig. 04).** This process takes place in autotrophic organisms, which use light as an energy source, carbon dioxide, and dissolved inorganic elements (mineral elements) to synthesize living organic matter. Organic matter can also be transferred to aquatic and terrestrial ecosystems in the form of leaves, fruits, and various organic debris (from plants and animals) that fall into water or soil, where they are decomposed by microorganisms.

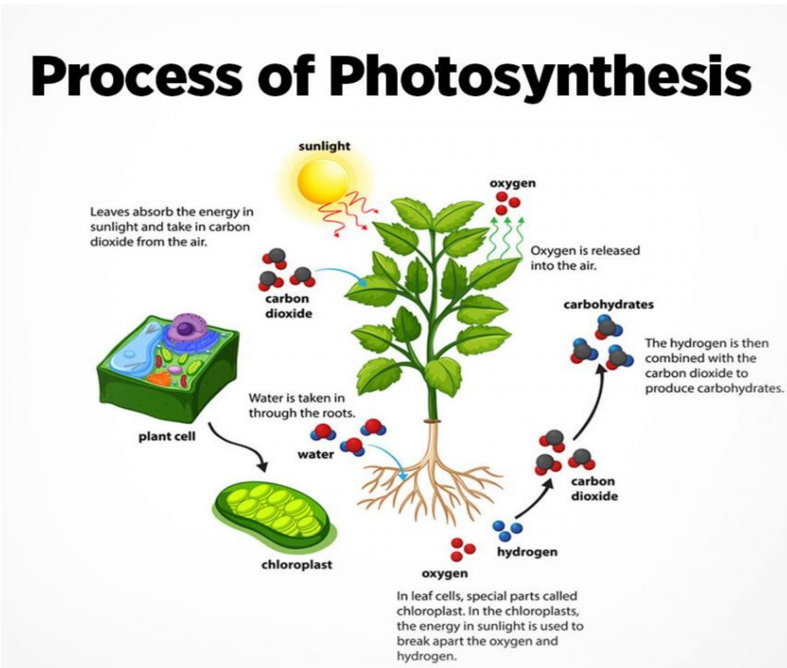

Figure 04. Photosynthesis process

2-3-3- Decomposition of Organic Matter:

The organic matter of dead organisms is broken down into organic or inorganic compounds **(Fig.05)**, either soluble or particulate. These processes use dissolved oxygen and result in the remineralization of nutrients, which are then reabsorbed by autotrophic organisms (the reverse transformation of organic matter into inert elements).

Decomposition is a phenomenon that contributes to the production of the energy required for other physiological mechanisms, such as respiration in natural species.

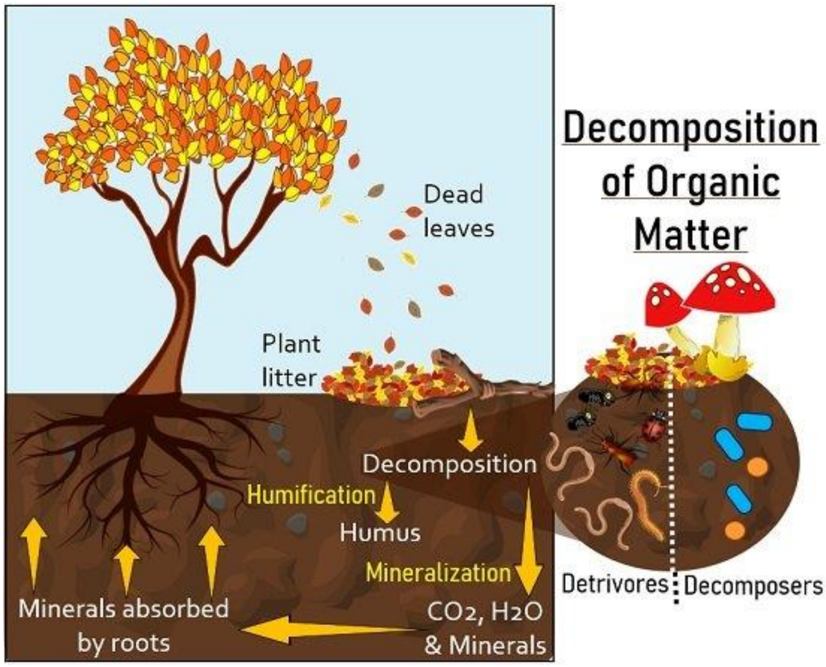

Figure 05. Decomposition of organic matter

2-3-4- Stages of Organic Matter Decomposition:

1. **Leaching:**
   Rainwater flowing through litter and soil degrades organic matter and can carry ions and soluble materials, resulting in the leaching of dissolved organic carbon.
2. **Fragmentation:**
   Large plant debris is broken down by soil fauna (saprophytes). These organisms feed by ingesting and partially digesting fragments of dead matter, cutting them with their mouthparts and moving them through the soil, forming "particulate organic matter."
3. **Incorporation:**
   Earthworms (anecic species), termites, and ants have a major impact on the movement of particulate matter from surface layers. These "soil engineers" help incorporate surface organic matter into deeper soil layers.

4. **Enzymatic Catabolism:**
5. Particulate organic matter also serves as an energy source for decomposer microorganisms (bacteria, fungi, archaea). These organisms produce extracellular enzymes capable of breaking certain chemical bonds within organic matter, releasing soluble sugars. The release of inorganic molecules (CO_2, and nutrient ions such as ammonium, phosphates, etc.) is called mineralization.
6. **Stabilization:**
   This stage marks the end of organic matter decomposition. Some molecules adsorb onto soil minerals and, once adsorbed, become less sensitive to enzymatic degradation. This process is referred to as the physicochemical stabilization of organic matter.

Table 06. Main decomposers of organic matter in nature

Group	Types according to their size	Description / Role
Decomposers	**Microflora**	Bacteria, fungi and the main primary decomposers. They can digest complex organic matter and transform it into simpler substances.
	Microfauna	Includes certain protozoa and nematodes that feed on microbial tissues or assimilate them and excrete mineral nutrients.
	Mesofauna	Small soil arthropods such as mites (*Acari*), springtails (*Collembola*), and Enchytraeidae. They fragment plant residues and dead matter and feed on primary decomposers.
	Macrofauna	Includes ants, termites, millipedes, and earthworms that decompose organic matter by breaking down plant debris and moving it through the soil profile, improving resource availability for microflora.