TD 3. Ecological consequences and ecotoxicological effects of water pollution

1) Ecotoxicology

Ecotoxicology is the science that studies the impacts of pollutants on the structure and functioning of ecosystems. These pollutants modify the distribution within the various compartments of the biosphere.

The effects of a pollutant depend on several factors, such as its behavior in the environment, the mode, and the route of administration of the pollutant. The main goal of ecotoxicology is prevention. To achieve this, ecotoxicology characterizes the risk of a substance as a function of:

(i) the **hazard** of the substance, and
(ii) the **probability of exposure** to that substance.

2) Concept of Hazard

Hazard depends on the intrinsic toxicity of the substance. This toxicity is evaluated in laboratories through tests conducted on different organisms in the trophic chain, allowing the determination of a concentration below which the substance has no harmful effects on the tested organism.

Two types of toxicity are distinguished:

- **Acute toxicity:** rapid and generally lethal effects following a very short exposure to a high concentration of a toxic substance. Pollutants are toxic at doses in the order of micrograms per liter. The concentration leading to acute toxic effects is higher than that leading to chronic toxic effects.
- **Chronic toxicity:** effects appearing after prolonged exposure to the substance, but imperceptible over a short time scale. The substance may express its toxicity in different ways. It can bioaccumulate in the tissues of the organism. After a sufficiently long latency period, the accumulated concentration exceeds the chronic toxicity threshold, and toxic effects are expressed. The substance may also cause slight symptoms at low concentrations; when these symptoms persist over time, they lead to significant dysfunctions of the organism.

The acute toxicity threshold is always higher than the chronic toxicity threshold.

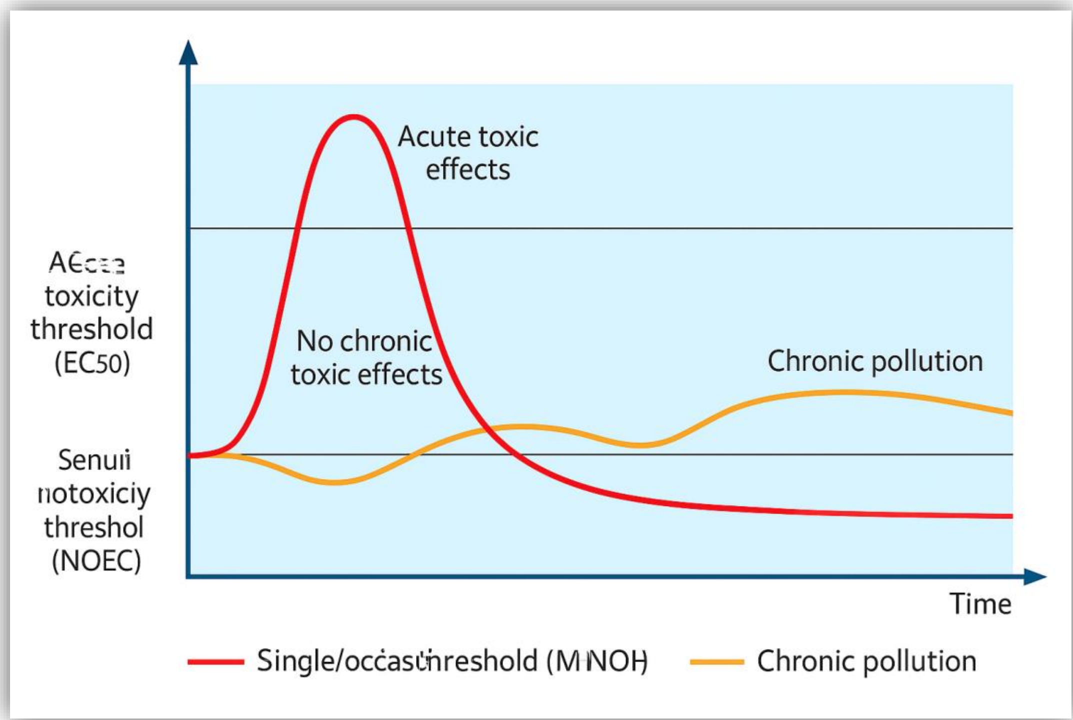

Fig. 1. Principles of acute and chronic toxicities

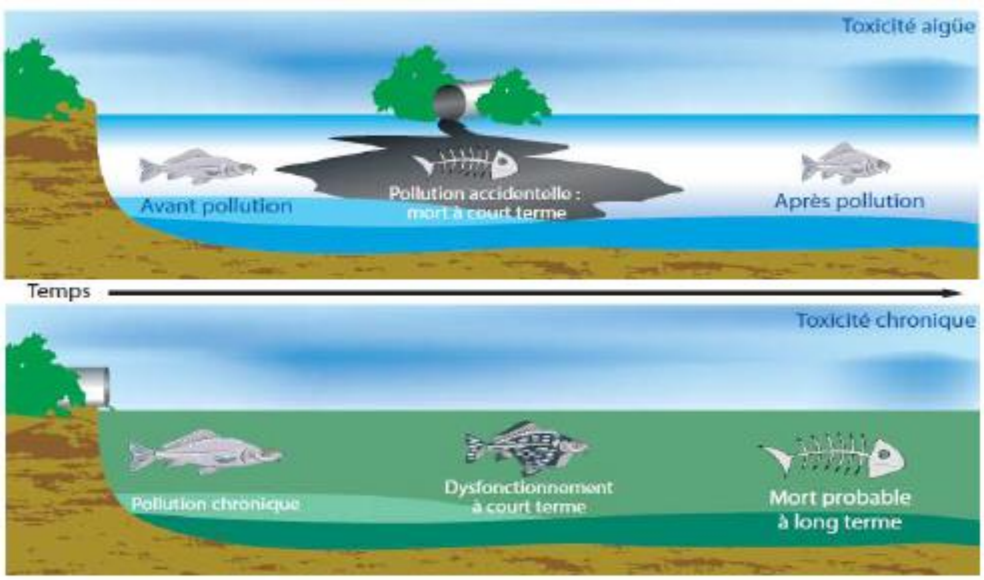

Fig. 2. Chronic or acute pollution: different toxicities

To evaluate the toxicity of a substance, standardized laboratory tests are used. The principle is to determine at which concentration a substance becomes toxic to an organism, in order to understand its effects on natural populations.

Living organisms are exposed to the test substances, and the effects of this exposure are observed. For an accurate evaluation, these tests must be performed on several organisms representing different trophic levels (usually: bacteria, algae, daphnia (microcrustaceans), and fish).

Example: Toluene

- Acute toxicity threshold = **6.3 mg/L** (tests performed on fish *Oncorhynchus kisutch* for 96 hours).
- Chronic toxicity threshold = **1.4 mg/L** (tests performed on the same species for 40 days).

3) Concept of exposure

The probability of exposure to a substance is related to all the factors that determine the fate of that substance in the environment.

It mainly depends on its physico-chemical properties, which influence the persistence and behavior of the pollutant in the natural environment, as well as on the characteristics of the receiving medium.

Exposure probability also considers the **duration** (continuous or occasional), the **route of exposure** (cutaneous, ingestion, inhalation, etc.), and the **individual exposed** (sex, age, etc.).

Exposure is therefore the result of the combination between **pollutant concentration** and **duration of exposure** to which organisms are subjected.

Some key factors influencing the fate and persistence of pollutants in aquatic environments include: **bioavailability**, **biodegradation**, and **bioaccumulation**.

a) Bioavailability

Bioavailability is defined as the ability of an element or a substance to reach the cell membranes of living organisms. It is one of the essential parameters of toxicity, since a change in the bioavailability of a pollutant corresponds to a change in its toxicity.

The **physical state** (adsorbed, dissolved) or **chemical state** (complexed, ionized) in which a pollutant occurs determines its ecotoxicity.

A pollutant within a given compartment can be both toxic and non-toxic for an organism, depending on whether it is bioavailable or not.

Example: Mercury (Hg) fixed in sediments is non-toxic for benthic organisms because it is **non-bioavailable**. Conversely, dissolved Hg in sediments is **bioavailable** and therefore toxic for sediment-dwelling organisms. Organisms living in open water (zooplankton, algae, pelagic fish) are less likely to be exposed to it.

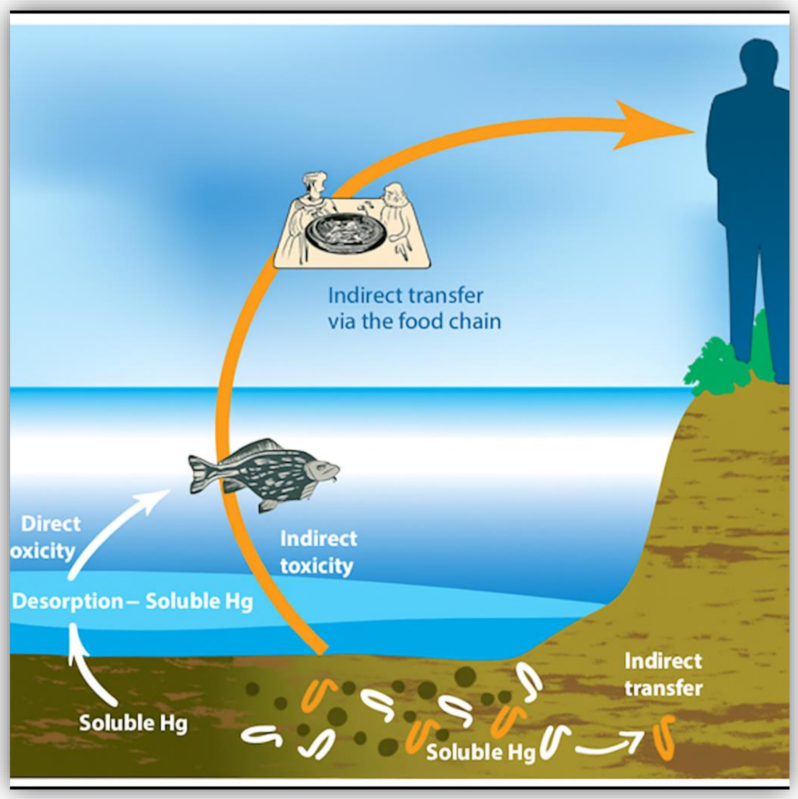

Fig. 3. Bioavailability: a key parameter of toxicity – the case of mercury

b) Degradation and Biodegradation

These are the main processes governing the fate of chemical substances in the environment.

Degradation refers to any physico-chemical process that leads to the more or less complete mineralization of a molecule.

Biodegradation is a biological degradation carried out by living organisms (bacteria, fungi, etc.). It depends on the abundance and diversity of microorganisms in the environment. The attack of a chemical molecule by microorganisms results in its mineralization and the formation of low-molecular-weight metabolites (also known as "by-products").

Two types of biodegradation are distinguished:

- **Primary biodegradation:** partial attack of the molecule. In some cases, this may result in the formation of persistent metabolites that are more bioavailable and/or more toxic than the original molecule.
- **Ultimate biodegradation:** complete degradation leading to the formation of carbon dioxide (CO_2), methane (CH_4), water (H_2O), and mineral elements. When rapid, this process leads to the **elimination of the pollutant** from the environment.

A substance undergoing **ultimate biodegradation** poses less risk to aquatic environments than one undergoing **primary biodegradation**.

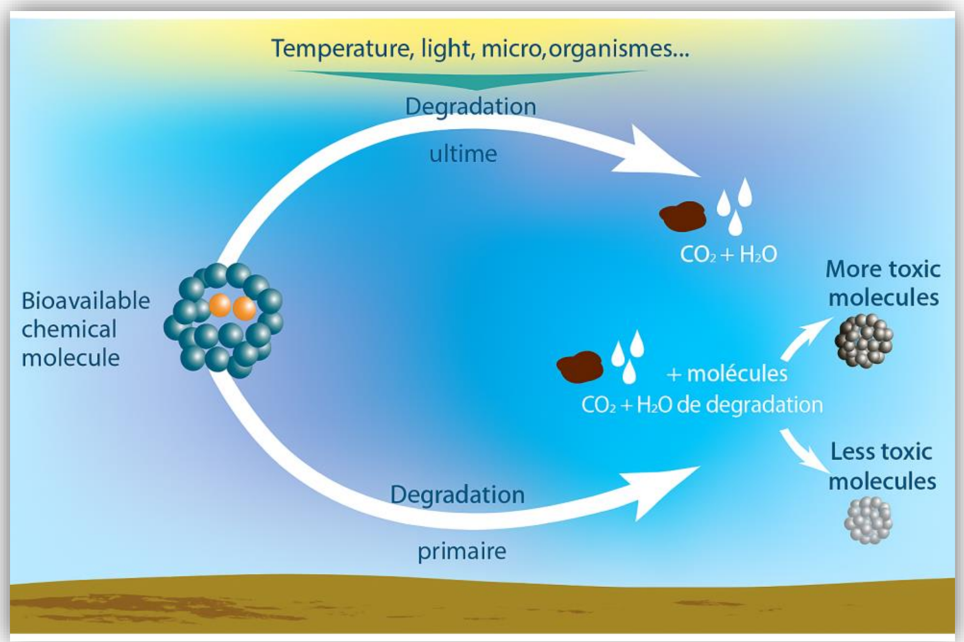

Fig. 4. Primary or ultimate degradation: a different level of risk

To assess the biodegradability of a substance, standardized methods based on bacterial degradation kinetics under laboratory conditions are used.

However, two easily measurable parameters can also be used:

- **BOD (Biochemical Oxygen Demand):** the amount of oxygen required by microorganisms to decompose all biodegradable organic matter.
- **COD (Chemical Oxygen Demand):** the amount of oxygen required to chemically oxidize all oxidizable substances.

Usually, **BOD_5** (oxygen demand over five days) is used. A substance is considered **easily biodegradable** if **$BOD_5/COD \geq 0.5$**.

Examples: Poorly biodegradable substances include **organochlorines (DDT)** and **PCBs**.

c) Bioaccumulation

Bioaccumulation refers to the accumulation of toxic substances in the tissues of living organisms. All living organisms are capable, to varying degrees, of accumulating toxic substances, which can result in **transfer** and **amplification phenomena** along the food chain. Higher concentrations are observed in organisms at higher trophic levels.

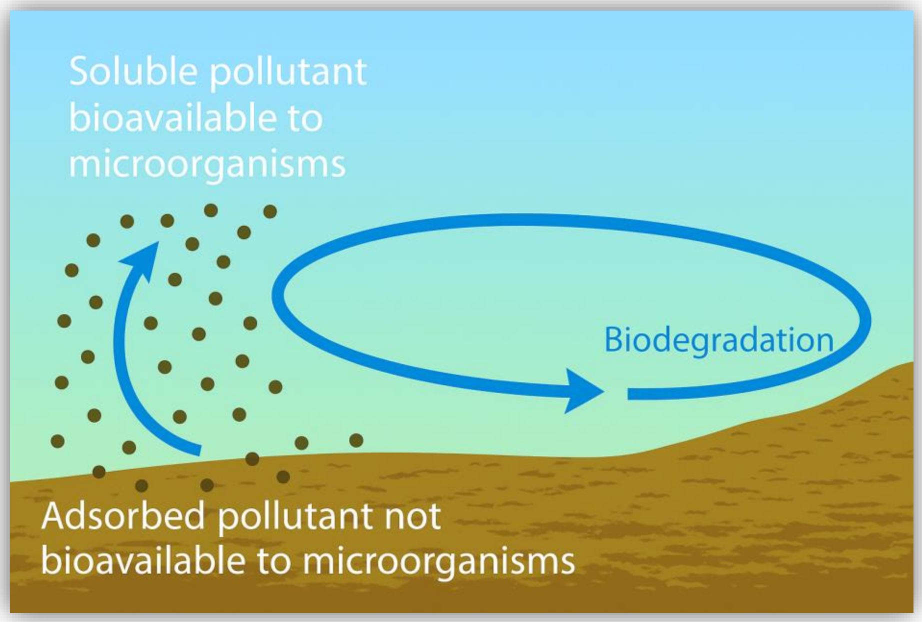

Fig. 5. Close relationship between adsorption, bioavailability, and biodegradation