Chapter 5. Ecological consequences of environmental pollution

5.1. Definition of pollution

Pollution is the degradation of the environment caused by the introduction into an ecosystem of substances that are not naturally present, leading to disturbances within that ecosystem. The consequences of pollution on living organisms range from health problems to the migration or extinction of species unable to adapt to environmental changes.

Thus, pollution is any anthropogenic modification of an ecosystem resulting in a change in the concentration of natural chemical components, or from the introduction into the biosphere of artificial chemical substances, disruption of energy flows, radiation intensity, matter circulation, or the introduction of exotic species into a natural biocenosis.

5.2 Air pollution

Air pollution is divided into three categories:

• **Local and proximity pollution:** This concerns emission sources of gases or other undesirable substances, most often produced in urban areas (industry, heating, traffic…). It primarily affects human health through its short-term direct effects, but also has long-term toxic impacts related to diseases such as cancer, asthma, and cardiovascular conditions.

• **Regional-scale pollution:**This concerns areas located tens (or even hundreds) of kilometers from emission sources. It mainly includes two phenomena: acid rain and photochemical pollution.

• **Global pollution:**

This includes two major issues:

- The depletion (“hole”) of the stratospheric ozone layer, mainly caused by halogenated compounds (chlorine, bromine, iodine) released by human activities.
- The increase in the greenhouse effect due to excessive production of certain gases (CO : carbon monoxide, CO_2: carbon dioxide, VOCs : volatile organic compounds), which will lead to major climatic changes (rising global temperatures and climate modifications affecting terrestrial life).

Air pollution may result from:

- **Quantitative changes**: increased concentrations of certain natural constituents of air (CO_2, NO_2, O_3),
- **Qualitative changes**: introduction of foreign compounds (radioactive elements, synthetic organic substances),
- **Or a combination of both**, which is most frequent.

With modern civilization, the quantities of substances released into the atmosphere altering its normal composition have steadily increased. The combustion of fossil carbon sources (coal, oil, natural gas) plays a major role in contaminating the air. Pollutants have very diverse atmospheric lifetimes, explaining the variety of spatial and temporal scales of pollution problems.

5.2.1 Types of pollutants

5.2.1.1 Primary pollutants

These are pollutants found directly at the emission source. For example, CO is a primary pollutant.

• Carbon monoxide (CO)

A colorless, odorless, lighter-than-air gas and one of the most abundant toxic atmospheric pollutants. Natural concentrations range from 0.005 ppm to 0.2 ppm throughout the troposphere.

• Sulfur Dioxide (SO_2)

Found only in trace amounts in the absence of pollution sources. In remote tropospheric areas, its average concentration ranges between 0.01 and 0.2 ppb.

• Nitrogen Oxides (NOx)

This group includes nitrous oxide (N_2O), nitric oxide (NO), and nitrogen dioxide (NO_2). They are mainly produced by combustion of fossil fuels (gasoline, diesel, fuel oil) or biomass. During combustion, atmospheric nitrogen reacts with oxygen at high temperatures to form NO, which gradually transforms into NO_2 in the presence of air. NOx are key precursors of photochemical ozone pollution.

5.2.1.2 Secondary pollutants

These pollutants are not emitted directly but result from physicochemical transformations of primary pollutants. Ozone, for instance, forms through reactions involving NOx and VOCs. Emission inventories can be produced for primary pollutants but not for secondary ones.

• Organic compounds: Volatile Organic Compounds (VOCs)

Organic compounds that easily vaporize and disperse in the atmosphere. They vary in degradability depending on microbial activity or chemical reactions (UV or ozone). Methane (CH_4) is considered separately from non-methane VOCs (NMVOCs).

Major families of VOCs:

- Alkanes (e.g., propane)
- Alkenes (highly reactive)
- Dienes and terpenes
- Mono- or polycyclic aromatic hydrocarbons (e.g., benzene, toluene)
- Oxygenated compounds (aldehydes, ketones, alcohols, esters)

Polycyclic Aromatic Hydrocarbons (PAHs)

Highly toxic, persistent, bioaccumulative, and often found in soot.

• Chlorofluorocarbons (CFCs) and Hydrofluorocarbons (HFCs)

CFCs were widely used before being banned by the Montreal Protocol (1987/1989) due to ozone depletion.

HFCs, while less harmful to ozone, have a global warming potential up to 14,000 times that of CO_2. They are being phased out under the Kigali Amendment (2016) with a planned elimination by 2050.

• Persistent Organic Pollutants (POPs)

Highly toxic, mutagenic, and carcinogenic industrial residues such as: TCE, TRI, dioxins, furans, PAHs, PCBs, HCB… These substances are semi-volatile and extremely persistent.

5.2.1.3 Particulate pollutants

• Heavy metals: Metals with high atomic weights (As, Cd, Cr, Cu, Hg, Ni, Pb, Se, Zn). Key examples:

- **Mercury:** volatile, combines easily, highly toxic; very sensitive to pH.
- **Lead:** formerly added to gasoline; causes saturnism.
- **Cadmium:** from waste incineration and industry; affects respiratory and digestive systems.

• Particulate matter (PM): Suspended liquid or solid particles, classified by size (TSP, PM10, PM2.5, PM1.0, ultrafine, nanoparticles).

5.3. Water pollution

Two major forms:

- **Point-source pollution**: household/industrial discharges, livestock effluents, treatable by wastewater plants.

- **Diffuse pollution**: pesticides, fertilizers across entire watersheds; difficult to treat.

These pollutants may be permanent, seasonal, or accidental.

5.3.1 Types of water pollution

5.3.1.1 Biological Pollution

• Microbiological pollution: Organic wastes, especially fecal matter, contain pathogens (viruses, bacteria, parasites) causing diseases such as cholera, typhoid, dysentery.

• Organic matter pollution: Comes from domestic, agricultural, and industrial wastes. Example: a city of 100,000 inhabitants discharges about 18 tons of organic matter daily.

• Pollution from invasive species: Example: *Caulerpa taxifolia* in the Mediterranean, which displaces native *Posidonia* meadows.

5.3.1.2 Chemical Pollution of Water

• Acid rain: Lowers pH and mobilizes toxic metals from sediments (Pb, Cd, Hg).

• Heavy metals: Examples:

- **Mercury:** Minamata disease (Japan, 1953), caused by industrial discharges.
- **Lead:** from fuel additives, accumulates in soils and runoff.
- **Cadmium:** from metallurgy, fossil fuels, industrial processes; present as impurities in fertilizers and contaminates soils and waters.

• Excess nutrients (N, P): Cause eutrophication (algal blooms, water turbidity, odor, weed proliferation).

5.3.1.3 Pollution by synthetic organic substances

• Pesticides: Toxic chemicals (insecticides, herbicides, fungicides…) largely used since WWII.
Transported to aquatic systems through runoff and infiltration.

• Detergents: Synthetic detergents (since 1950) contain toxic ingredients affecting water properties and aquatic life; include anionic, nonionic, and cationic detergents.

5.3.1.4 Thermal pollution

Discharge of heated water (4–5°C warmer), especially from power plants, disrupts aquatic ecosystems by lowering dissolved oxygen and altering species' physiological cycles.

5.4. Soil pollution

Soil pollution can be local or diffuse, originating from agriculture, industry, or microorganisms, affecting soils and groundwater.

• Agricultural pollution:

Includes pesticides and excess nitrates, which leach into groundwater and may cause health problems (e.g., nitrate-induced anemia).

• Industrial and microbial pollution:

Often point source, affecting groundwater. Some aquifers may become unusable for decades. Dense non-aqueous phase liquids (DNAPLs), used in dry cleaning, wood preservation, and machining, sink rapidly and contaminate large volumes of water.