

Chapter 6. Consequences of pollution on different ecosystems

6.1 Acid Rain

Acid rain is a form of atmospheric pollution that is currently the subject of significant controversy due to the extensive environmental damage it is believed to cause. Acid rain forms when sulfur and nitrogen oxides combine with moisture in the air to produce nitric and sulfuric acids, which can then be transported far from their sources before falling as precipitation.

Rain is naturally slightly acidic (pH around 5) because it contains acids resulting from reactions of atmospheric carbon dioxide and chlorine with moisture. When precipitation has a pH below 5, it is considered acid rain.

6.1.1 Origin of acid rain

Human activities are responsible for releasing large quantities of pollutants into the atmosphere, particularly sulfur dioxide (SO₂), carbon dioxide (CO₂), and nitrogen oxides (NO_x).

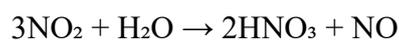
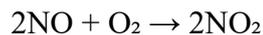
6.1.2 Formation of acid rain

Acid rain can be produced by two major pollutants:

- Nitric oxide (NO)
- Sulfur dioxide (SO₂)

Two chemical reactions occur:

For NO:



For SO₂:



Both initial molecules react with atmospheric oxygen and dissolve in water droplets. Nitric oxide mainly comes from vehicle exhaust gases. Sulfur dioxide results from the combustion of fossil fuels containing sulfur.

Additionally, atmospheric CO₂ slightly acidifies cloud water. Volcanic gases and aerosols are also acidic and can contribute to acid rain.

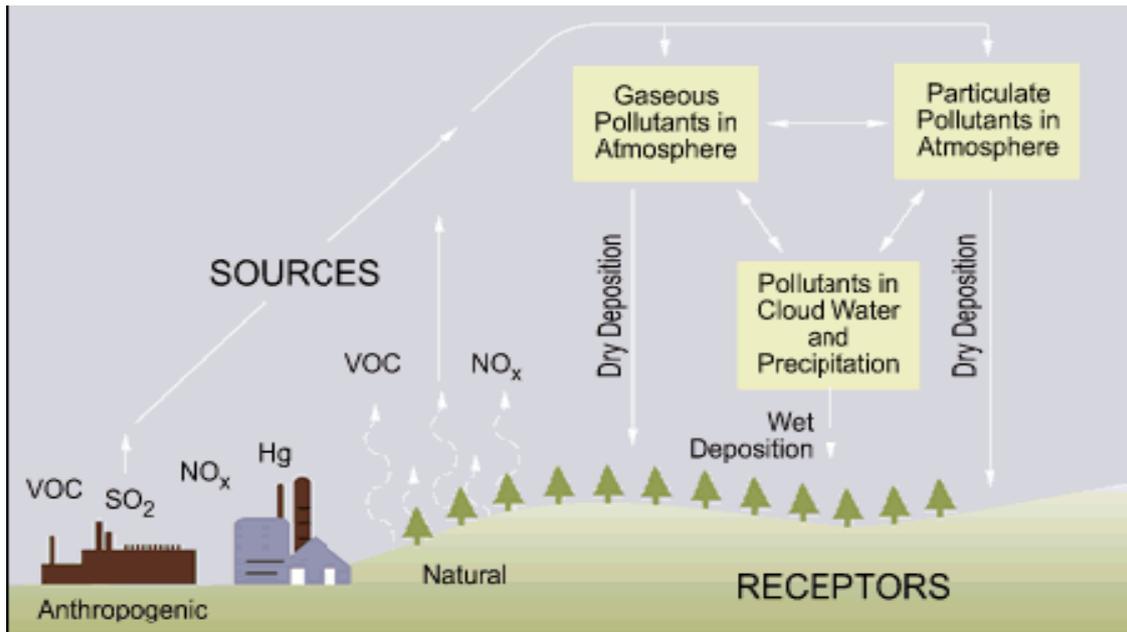


Figure 16. Formation of Acid Rain

6.1.3 Consequences of acid rain

A) Human health

Children, the elderly, and individuals with respiratory or cardiovascular diseases experience worsened health when exposed to acidic smog or acid rain.

B) Water and lake ecosystems

The more acidic a lake becomes, the fewer species it can support. Plankton and invertebrates are among the first organisms to die, disrupting the entire food chain.

C) Materials (Corrosion)

As precipitation washes pollutants from the atmosphere, many materials and monuments are vulnerable to degradation.

Acid rain accelerates corrosion of limestone, sandstone, marble, brick, cement, and metal, causing serious damage to old buildings, sculptures, and outdoor monuments. It dissolves calcium carbonate, leaving salt crystals that expand and crack the stone as they grow.

D) Plants and Forests

Acid rain contributes to forest decline by altering the permeability of leaf cuticles. It leaches essential nutrients and minerals from soils before trees can absorb them.

Toxic elements like aluminum are also released, impairing nutrient uptake. Nutrient-deficient trees grow slowly, lose leaves, and become more vulnerable to climatic stress, pests, and disease. A forest's tolerance to acid rain depends on the soil's neutralizing capacity.

E) Soils

Acid precipitation alters soil chemistry by increasing acidity, resulting in the loss of essential nutrients. Sandy soils are highly sensitive and easily leached.

6.2 The Ozone hole

Ozone (O_3) is a reactive and unstable form of oxygen. The ozone layer corresponds to the atmospheric region where its concentration is highest between 15 and 40 km in the stratosphere. Its concentration results from a balance between formation and destruction, influenced by solar activity, temperature, and the presence of other chemicals. Ozone forms under the action of sunlight on oxygen, mainly over tropical regions, and is transported toward the poles by air circulation.

Despite this, its concentration remains low, only a few parts per million. An ozone hole occurs when ozone concentration falls below **220 Dobson Units** (normal value ≈ 400 DU).

6.2.1 Origin of pollutants

Chlorofluorocarbons (CFCs), consisting of carbon, fluorine, and chlorine, were widely used because they are stable and non-toxic. They were used in:

- Refrigeration and air conditioning systems
- Aerosol propellants
- Solvents for cleaning electronics and mechanical parts
- Foaming agents in plastic production

Halons (bromine-containing compounds) were used in fire extinguishers. Other substances involved in ozone depletion include:

- Chlorinated solvents
- Methyl bromide (used in horticulture)
- HCFCs and HFCs (developed to replace CFCs but still contributing to greenhouse effect)

Under sunlight, these compounds release chlorine atoms that break down ozone. A single chlorine atom can destroy thousands of ozone molecules and remain in the atmosphere for up to 100 years.

6.2.2 Evolution of the ozone hole

European data show a 5.4% decrease per decade since the 1980s during winter and spring, with slight improvement between 1995–2000.

In 2000, 2001, and 2003, the ozone hole reached unprecedented sizes—up to **28 million km²** in September 2000.

In 2003, it again expanded to 25 million km² (the size of North America). The World Meteorological Organization attributes such fluctuations to yearly variations in stratospheric meteorological conditions, not to total amounts of ozone-depleting substances.

6.2.3 Consequences of the ozone hole

- a) **Increased UV-B radiation reaching the surface**, causing sunburn, DNA alterations, skin cancers (melanoma), and eye damage.
- b) **Threat to plant metabolism**, particularly photosynthesis, reducing growth in crops such as soybeans and tomatoes.
- c) **Impact on marine plankton**, which orients itself according to light intensity. UV-B disrupts this orientation, causing plankton to sink and die from lack of light or burn at the surface. Plankton mortality threatens marine food chains and could affect oceanic oxygen production ($\approx 50\%$ of Earth's oxygen).

6.3 The Greenhouse effect and climate change

6.3.1 The Greenhouse effect

A greenhouse is a glass-covered structure that allows sunlight in but traps heat. Similarly, naturally occurring greenhouse gases trap heat in Earth's atmosphere.

Main natural greenhouse gases:

- Water vapor (2–3% of the atmosphere)
- Carbon dioxide ($\approx 0.035\%$)

Without the greenhouse effect, Earth's average surface temperature would be -15°C instead of $+15^{\circ}\text{C}$.

The term "**greenhouse effect**" is often misused; "**global warming**" or "**climate change**" is more accurate.

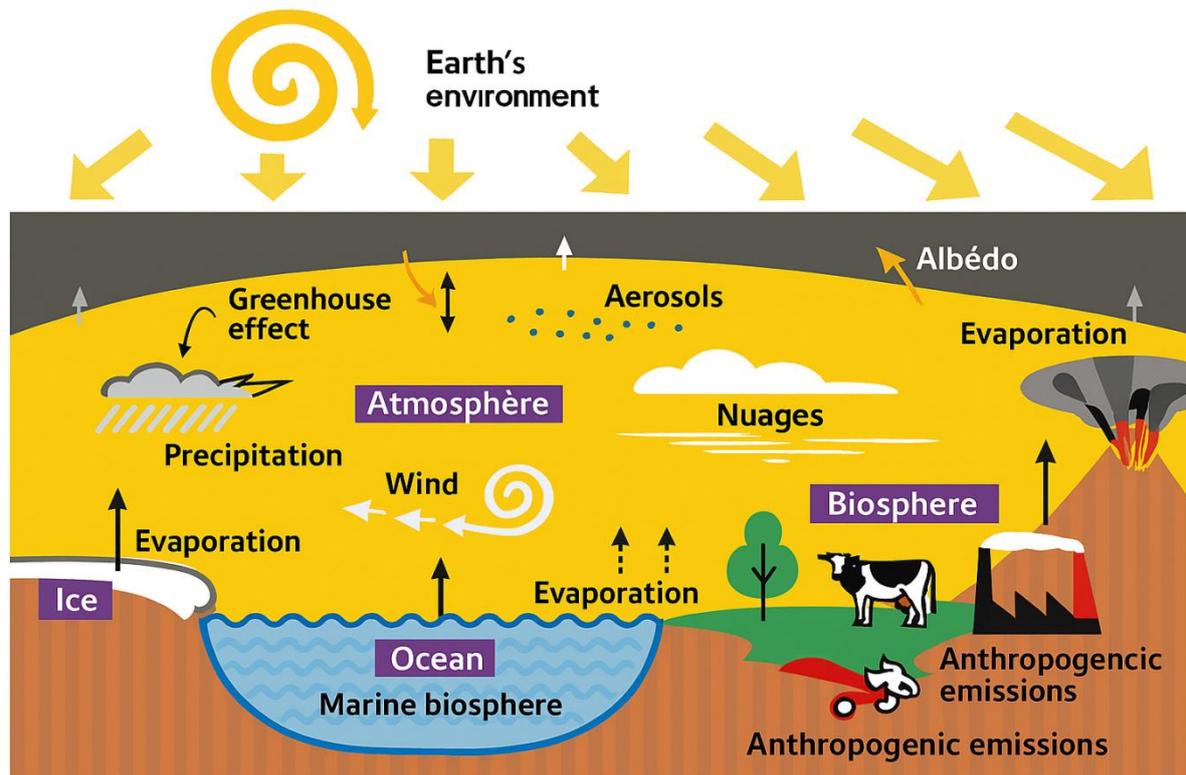


Figure 17. Mechanism and Functioning of the Greenhouse Effect on Earth

6.3.1.1 Types of greenhouse gases

Naturally present greenhouse gases include:

- Water vapor (H_2O)
- Carbon dioxide (CO_2)
- Methane (CH_4), produced in wetlands and by ruminants or termites
- Nitrous oxide (N_2O), emitted by oceans and soils

6.3.2 Climate Change and Its Consequences

6.3.2.1 Temperature Trends

Since 1840, Earth has warmed by about $0.6^\circ C$. Warming has occurred in cycles, but long-term trends show clear planetary warming. The hottest years since 1880 have occurred in recent decades (e.g., 1998). Human activities (greenhouse gas emissions, aerosols) significantly contribute. Models predict a $3^\circ C$ increase by 2100 compared to current temperatures.

6.3.2.2 Sea level rise

A rise of about **50 cm** is expected by 2100 due to: Ocean warming, melting mountain glaciers and melting ice caps and Antarctic ice sheets

6.3.2.3 Environmental consequences

- Permanent flooding of low-lying lands and islands
- Loss of coastal territories
- Increased frequency of temporary flooding (storms, high tides)
- Accelerated coastal erosion (beaches, dunes, cliffs)
- Salinization of estuaries, groundwater, wetlands, and farmlands
- Altered river hydrology, affecting flood dynamics

6.3.2.4 Impact on vegetation

Regions currently dominated by tropical grasslands may become temperate grasslands or deserts by 2080. Tropical forests are already turning into savannas or deserts (e.g., northern Brazil). Models predict major biodiversity loss beginning around 2050.

6.3.2.5 Impact on ecosystems

Changes in the water cycle runoff, humidity, sedimentation, decomposition affect:

- Plant productivity
- Competition among species
- Biodiversity

Aquatic animals (fish, birds, mammals) are affected by temperature changes, water quality, currents, food availability, and predators.

6.3.2.6 Impact on Human Health

The World Health Organization warns of:

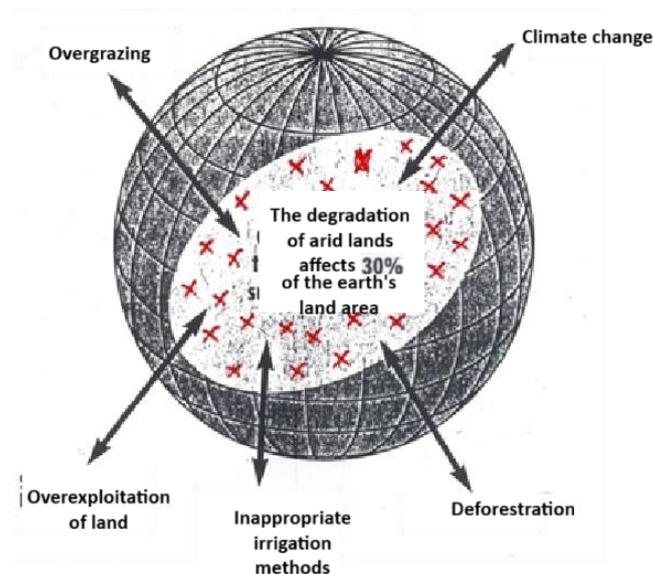
- Heat stress
 - Respiratory disorders caused by climate and poor air quality
 - Expansion of disease-carrying vectors in northern regions
- Ecosystem changes may also promote allergenic plant species, increasing asthma and allergy cases.

6.4 Desertification

Desertification is the degradation of land in arid, semi-arid, and dry sub-humid regions due to climate variations and human activities.

It manifests as deterioration of vegetation cover, soils, and water resources, ultimately reducing the land's biological productivity.

6.4.1 Causes of desertification



6.4.2 Most Threatened regions

More than 110 countries have arid lands threatened by desertification. Africa, Asia, and Latin America are most affected. In many developing regions, desertification is associated with increasing poverty.

- 1 billion hectares affected in Africa
- 24 billion tons of topsoil lost globally each year
- 70% of 5.2 billion ha of arid land worldwide degraded
- 1.4 billion ha threatened in Asia
- 74% of North American land degrading
- Several EU countries also affected

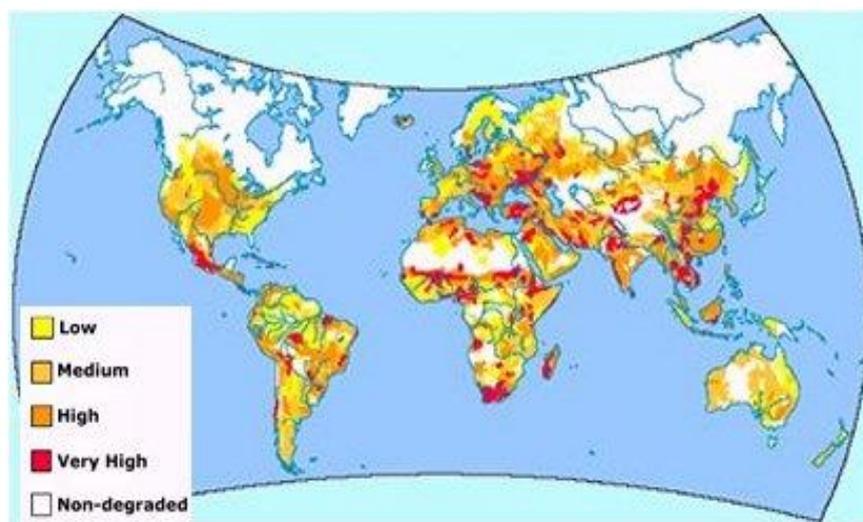


Figure 20. Extent of Desertification Worldwide