Land salinization

1. Soils affected by salinity

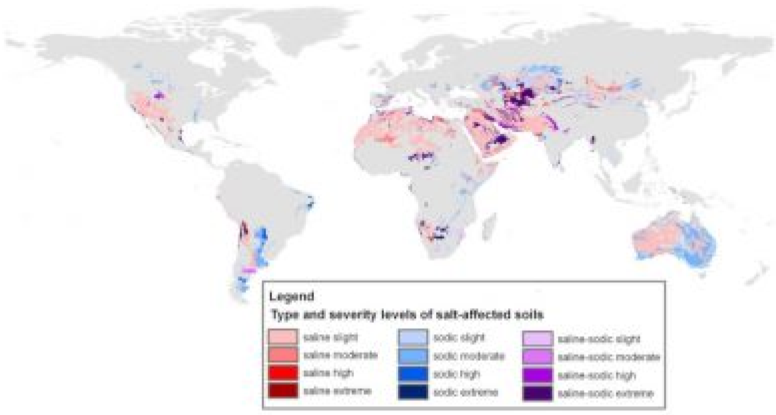

Figure 1. Distribution of saline soils in the World. [Source: Wicke et al, 2011; ref. 1]

An estimate indicates that **7% of the world's land area** is affected by salinity. The global extent of salt-affected land amounts to about 1.1 GHa, of which 14% is classified as forests, wetlands or (inter)national protected areas and is considered unavailable for biomass production due to sustainability concerns (Figure 1). [1]

Natural environments can be affected by the presence of salts in the soil or water table resulting from the **alteration of** mineral-rich **rocks** put in place during geological time. Many areas are thus subject to **primary salinization**, which develops naturally as a result of the long-term continuous flow of salt-laden groundwater. A number of **salt lakes** (Figure 2) formed in this way contain ecosystems adapted to these extreme conditions (See Microbes in Extreme Environments).

Figure 2. Salt Lake of Tajikistan. [Source: Pixabay]

It is mainly **sodium chloride** (**NaCl**), the most soluble, calcium and magnesium chlorides, and to a lesser extent carbonates and sulphates that are responsible for the salinity (see Figure 1).

2. Agricultural soils lost due to salinization

2.1. Secondary salinization

Human activity is responsible for the salinization of soils, which are then made unfit for agriculture. This is known as **secondary salinization** (Figure 3).

Figure 3. Aerial view of fields with salt upwelling at the surface (California Valley, USA). [Source: Scott Bauer / Public domain]

The *Food and Agriculture Organization* of the United Nations estimates that **20% of the World's irrigated land** is affected by salinity problems [2]. Every year, 10 million hectares of agricultural land are destroyed worldwide by soil salinization.

Climate change, overuse of **groundwater**, increasing use of **poor quality** irrigation water, massive irrigation in a **semi-arid to arid** climate zone and lack of soil **leaching** [3] may intensify this phenomenon of soil salinization.

2.2. Example of the Murray-Darling Basin

In south-east Australia, the Murray-Darling Basin, the largest on this continent, is threatened by salinisation. A basin is the area of a country drained by a series of rivers and their tributaries that flow into the sea at a single mouth.

Figure 4. Murray-Darling Basin. Aerial photo of farmland on the Murrumbidgee River, a tributary of the Murray River (left). Murray-Darling Basin (in dark green). [Source: Left, CSIRO / CC BY 3.0) / Right, Wikimedia Commons / CC BY-SA 4.0]

The Murray-Darling Basin (Figure 4) accounts for 1/7 of Australia's land area, provides 40% of its agricultural production, and supports 3 million people.

The causes of this disaster are irrefutable: human activities linked to European colonization are responsible for the salinization of the soils of the Murray-Darling Basin (Figure 5):

- The gold rush caused **massive deforestation** in the area. These forests, by absorbing rainfall, prevented the filling of aquifers, wh groundwater bodies.

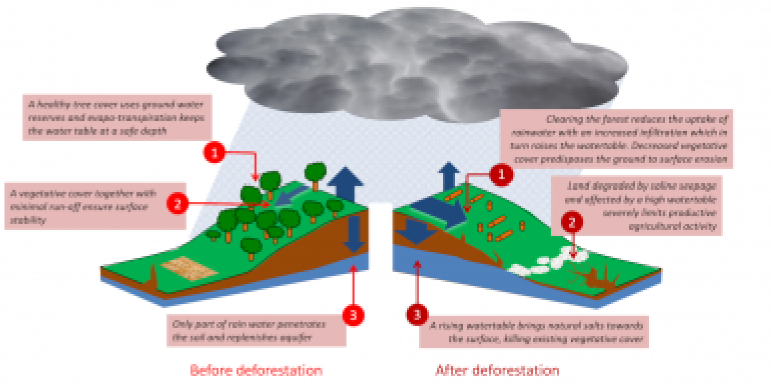

Figure 5. Secondary salinization. Example of the Murray-Darling Basin (Australia). On the left, the diagram illustrates the ecosyst before deforestation, where the forest absorbs rainfall, thus preventing aquifer recharge. After deforestation, the aquifers fill up a come up, causing salt to rise to the surface of the ground (right). [Source: © Murray-Darling Basin Commission]

- Deforestation caused a gradual **replenishment** of shallow aquifers [4].
- Unfortunately, these **aquifers** are naturally **charged with salt**. At one or two meters from the surface, water loaded with salts rise capillarity.
- Within 150 years, the soil horizons are successively **contaminated by salt** until they form a **deposit on the surface** due to evapo

2.3. Irrigation & salinity

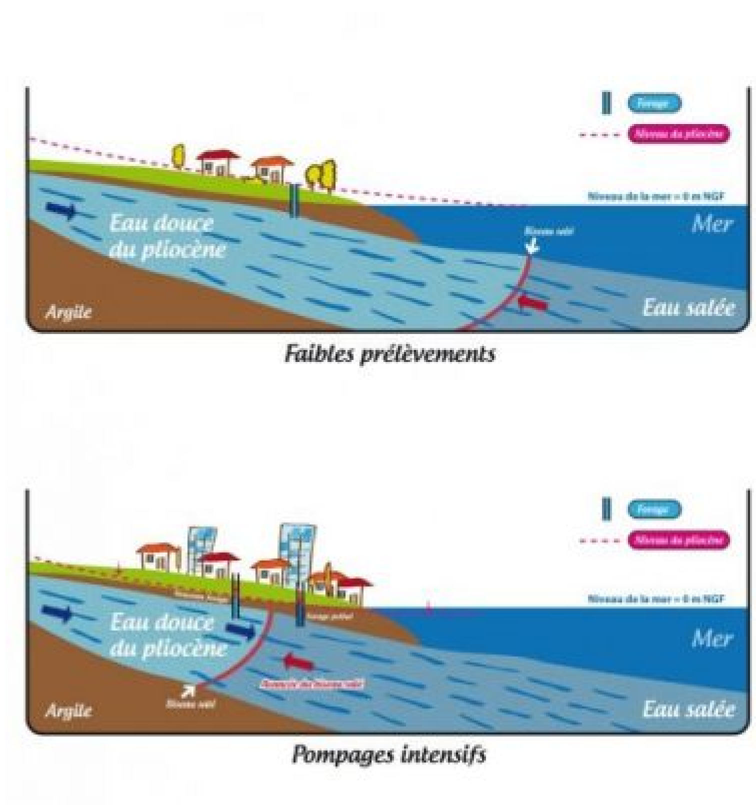

Figure 6. Intrusion of seawater into the slicks. At the top, a reasonable pumping of the slick maintains its level thanks to natural recharge. If human activity requires more withdrawal, saltwater intrusion from the sea into the aquifer occurs, making it brackish (bottom). [Source: © Syndicat Mixte pour la protection et la gestion des nappes souterraines de la plaine du Roussillon] [5]

In **arid to semi-arid areas** with insufficient rainfall, agriculture cannot do without irrigation. Unfortunately, if irrigation is carried out with water from **salt-laden aquifers**, it will cause an increase in **salt** in the root zone. Low rainfall or the impossibility of irrigating with fresh water prevents leaching to get rid of the excess salt in these soils. As a result, irrigation water is transferred from the soil to the atmosphere by transpiration and evaporation of plants, leaving salts dissolved in the soil and increasing salinization.

Human activity with the **pumping of freshwater** into coastal aquifers causes **saltwater intrusion** that reduces water quality. Figure 6 describes this intrusion:

- reasonable pumping of the water table maintains its level through **natural recharge**.
- if human activity requires a greater withdrawal, salt water from the sea intrudes into the groundwater table, making it **brackish**.

2.4. Soil salinity and sea level rise

Finally, soil salinity due to **sea level rise**, seawater infiltration by waves, wind transport of sea spray or storms causes problems for coastal agriculture. Examples on this subject abound. One example is the problems of salinization of **rice fields in the Mekong Delta** in Vietnam, which suffer not only from seawater intrusion, but also from the reduction in the flow of this great river caused by the construction of upstream dams that prevent optimal leaching of saline soils. There are also problems of salinization of soils on which **vines** grow in **the Hérault** (South of France) [6].

3. Deleterious effects of sodium on soil structure

The **sodium (Na^+) cation** not only impairs plant growth and development, but also causes **soil destructuring**. These problems, which are increasing worldwide, require agriculture to use soil management techniques to reduce its harmful effects.

Excess sodium (Na^+) in the soil **changes the physico-chemical properties of** the soil. Soil is composed of solid, liquid (water and dissolved elements) and gaseous constituents:

- The solid constituents of the soil are composed of **organic matter** (resulting from the degradation of plants and animals, dejecta, ...) and **mineral matter**.
- The mineral matter is composed of a coarse fraction (gravel, ...) and a fine fraction (clay, ...).
- The **clays** are in the form of particles of less than 2 µm which serve as a "glue" for the larger elements. Thus, clays constitute the mineral colloidal fraction of the soil and give the soil its physico-chemical properties.

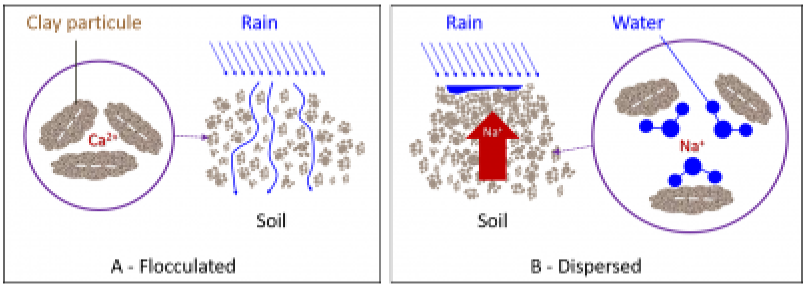

Figure 7. Effect of sodium on soil structure. A, Ca2+ allows a good flocculation of the clays (negatively charged) which makes the soil permeable to water. B, In the presence of Na+, this cation reacts with water, which will reduce flocculation and disperse the clays, producing a compact soil impermeable to water. [Source: © EEnv diagram]

Clays have negative charges on their surface; they repel each other naturally and remain in suspension. In the presence of protons (acid medium) or cations to neutralise their charges, clays clump together and precipitate; this is called flocculation (Figure 7). The cations Ca^{2+}, Mg^{2+} and Al^{3+} allow a good flocculation of clays, unlike H^+, K^+, and Na^+.

The binding intensity of bivalent cations to clays is higher than that of monovalent cations, mainly due to a higher hydration shell in K^+ and Na^+ ions. Thus, **Na^+ provides the least stable flocculation** compared to other positive ions.

- Na^+ remains mostly in solution, but it can also replace a small proportion of Ca^{2+} and Mg^{2+} ions on clays, which is known as the **proportion of exchangeable Na^+**.

- Na^+ ion will act with fresh water (during rainfall or irrigation) to form a **strong base**, significantly alkalizing the soil and producing the hydroxide ion OH^-. The combination of the latter with the H^+ ion will cause the loss of H^+ ions adsorbed on the clays, reducing their flocculation.

The excess Na^+ ion in the soil therefore has a **strong dispersing effect** on clays (Figure 7B).

Dispersed clays produce a **compact and asphyxiating soil** for the roots, whereas in the flocculated state, clays promote aeration, water permeability and the life of beneficial microorganisms.

Salinized soils are classified according to:

- their electrical conductivity value (in S/cm) which is related to the salt concentration ;
- their proportion of exchangeable Na^+;
- their pH.

The proportion of exchangeable Na^+ is closely related to the ratio :

$$\frac{[Na^+]}{\sqrt{\frac{[Ca^{2+}]+[Mg^{2+}]}{2}}}$$

Where the concentrations of Na^+, Ca^{2+} and Mg^{2+} are expressed in **milliequivalents/L**; the higher the value, the more Na^+ will interfere with the flocculation of the clays.

The classification then includes **saline, sodic and saline-sodic** soils (Table 1).

Classification	Electric conductivity (dS/m)	Proportion of exchangeable Na^+
Saline	>4	<13
Saline-sodic or salsodic	>4	>13
Sodic	<4	>13

Various agricultural practices can **limit the harmful effects of** excess salt on plant cultivation [7]. When these practices are unfortunately no longer effective, and in particular in the context of saline soils rehabilitation, the removal of salt that has accumulated on the soil surface by **mechanical means** temporarily improves crop growth.

Flooding the plots with fresh water also helps to desalinate the soil [8]. The supply of fresh water by infiltration into the soil dissolves excess salt and eliminates it if this water is well drained; this is called **leaching**. This is the most effective procedure for removing salt from the root zone of soils. **Drainage** is important here to avoid increasing the water table in salt. Other solutions such as **adding organic matter** to the soil can also be used [9].

Notes and References

Cover image. Aerial view of fields with salt rising to the surface (California Valley). [Source: Scott Bauer / Public domain]

[1] Wicke B, Smeets E, Dornburg V, Vashev B, Gaiser T, Turkenburg W & Faaij A (2011) The global technical and economic potential of bioenergy from salt-affected soils. *Energy Environ Sci* 4:2669-2681. https://doi.org/10.1039/C1EE01029H

[2] In the European Union, the Mediterranean countries are mainly concerned by this problem (France, Greece, Italy), but also Bulgaria, the Czech Republic, Germany, Hungary, Portugal, Romania and Slovenia. Toth G, Adhikari K, Varallyay G, Toth T, Bodis K & Stolbovoy V (2008) Updated map of salt affected soils in the European Union. In: Toth G, Montanarella, L. & Rusco, E. (ed) Threats to Soil Quality in Europe. Office for Official Publications of the European Communities, Luxembourg, pp 65-77].

[3] Leaching refers to the process by which soluble compounds unsuitable for cultivation are removed from the soil by water. It differs from the term leaching, which refers to non-soluble compounds.

[4] https://www.mdba.gov.au/sites/default/files/archived/mdbc-salinity-reports/2072_Salinity_audit_of_MDB_100_year_perspective.pd

[5] https://www.nappes-roussillon.fr/L-intrusion-saline.html (in french)

[6] https://france3-regions.francetvinfo.fr/occitanie/vignes-serignan-meurent-intoxication-au-sel-mer-546726.html (in french)

[7] http://www.fao.org/tempref/agl/IPTRID/salinity_brochure_fr.pdf

[8] https://www.mon-viti.com/articles/viticulture/quand-le-sel-ronge-les-vignes (in french)

[9] http://www.fao.org/soils-portal/soil-management/management-of-some-problem-soils/salt-affected-soils/more-information-on-salt-a