

Chapter 6:

Soil Degradation



*We abuse land because we regard it as a commodity belonging to us.
When we see land as a community to which we belong, we may begin to use it
with love and respect.*

- Aldo Leopold, 1949. A Sand County almanac.

6.1 Introduction

In Chapter one, we discussed that soil mismanagement and degradation was responsible for the rise and fall of ancient civilizations. It is without a doubt that humans and soils have evolved mutually throughout history; human survival has been linked to the health of the soil, and the health of the soil has been linked to the humans that use it.

When inappropriate human use, or perhaps abuse, of the land renders it less vigorous and less healthy, we say that the land has been *degraded*. Soil degradation occurs as a result of both natural and human-induced processes that reduce its potential productivity. Changes in the physical, chemical, and biological nature of the soil that are brought about by inappropriate land-use practices and bad management reduce the soil's ability to support plant and animal growth. The soil may decline in available moisture, nutrients, and biological activity. The result is a loss of arable land that is essentially irreversible within the human lifespan.

During the past 50 years, inappropriate land use has degraded about 5 billion ha of the Earth's vegetated land. The figure amounts to approximately 23% of the world's previously usable land and is expanding at a rate of 9 million ha per year (Soil Degradation). Figure 6.11 shows the distribution and severity of the world's degraded soils in 1997.

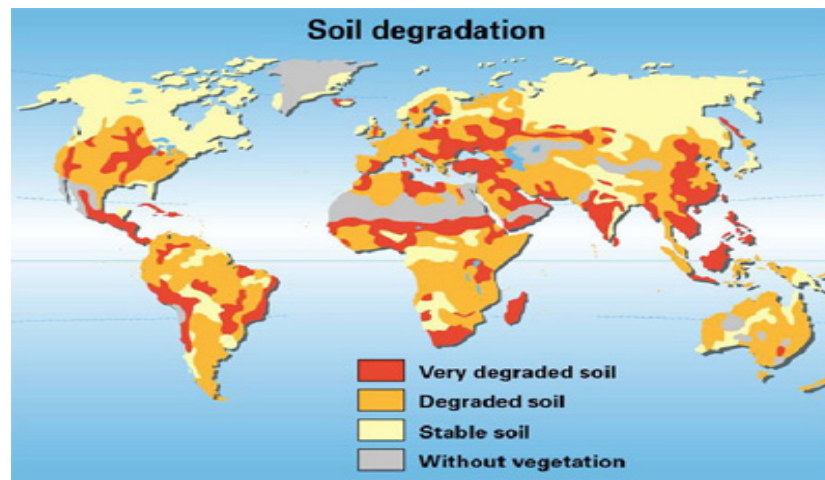


Figure 6.11: The state of soil degradation in the world in 1997.

Source: Soil Degradation

Soil degradation is a result of economic, social, and political pressures on the land. It occurs primarily due to overgrazing (35%), deforestation (30%), agricultural activities (27%), overexploitation of vegetation (7%) and industrial activities (1%) (Land Degradation). The results are generally viewed as erosion, loss of organic matter, salinization, and acidification.

In this chapter we will explore how changes in the physical, chemical, and biological state of the soil can cause soil degradation. The problems and implications of each type of degradation will be discussed.

6.2 Organic Matter Depletion

The total organic matter content retained by the soil system is a function of the organic matter gains and losses. The quantity of organic matter entering the soil is determined by primary production of plants, and the amount leaving is controlled by erosion and microorganism decay of OM.

The organic matter content of the soil depends on texture, drainage, natural vegetation, and erosion. In general, sandy soils have less organic matter than clay loams and clay; well drained soils less than poorly drained ones; soils developed under trees less than those developed under grasses; and eroded soils less than those which have not been subject to past erosion.

The role of organic matter in soil is exceptionally important, as its influences reach all physical, chemical, and biological properties of the soil. Without organic matter as a cementing agent, soil particles would not be able to bind together to form aggregates that strengthen and stabilize the structure of the soil. The soil would become weak and easily prone to erosion. Soil porosity and water-retention would also be reduced, meaning that any incident precipitation would be inhibited from entering the surface of the soil and result in runoff.

Soil organic matter also contains a huge portion of the soil's essential nutrient reserves and accounts for more than half of the soil's cation exchange capacity. Nutrients such as phosphorous, nitrogen, sulphur, and micronutrients are safely stored on the surface of organic colloids to be taken up by plants when needed. Organic matter is also one of the main resources that supply organisms with the energy needed for growth and reproduce.

The removal or depletion of organic matter can have harmful impacts on the soil system. Depletion occurs when the quantity of OM entering the soil is decreased and the amount of OM leaving the soil is increased. For example, the removal or burning of crop residue prevents fresh organic material from entering the soil. Tillage increases the rate of organic matter breakdown by soil organisms. Physical removal of topsoil by wind and water erosion dramatically reduced the OM content since the topsoil is the area of highest OM concentration.

Soil degradation due to organic matter removal can have dire consequences on ecosystems.

6.3 Soil Salinization

Salinization occurs when water soluble salts – sodium, potassium, calcium, magnesium, and chlorine – accumulate in excess concentrations in the root zone of plants to such an extent that they lead to degradation of soil and vegetation. When salinization of the soil is due mainly to the concentration of excess sodium, it is referred to as *sodicity*.

Soil salinization is a physical and biochemical problem with grave consequences. The build-up of excess salts can severely decrease the osmotic potential of the soil. When the soil has a lower osmotic potential, the concentration of solute in the soil is higher than that of the root. Thus, the plants must exert a much greater force to extract water from the soil. If the concentration of salts in the soil is so high that plants are unable to extract any water, the plant may wilt and die. A decline in the osmotic potential of the soil can hinder the growth and yield of crops by limiting water take-up and is therefore detrimental to plant growth.

Sodic soils also experience degradation of soil structure than can be problematic for plant and crop growth as well as support of infrastructure. Sodium causes clay and organic matter of the soil to disperse. The soil becomes compacted and hampers the growth of roots. When sodic soils become dry, the sodium-clay forms a hard crust that is characterized by a white surface coating. Crusted soils are impenetrable to plant roots and may even limit the emergence of seedlings.

Soil salinization may occur naturally or due to conditions resulting from anthropogenic mismanagement of the land. Salinization occurs when conditions of low rainfall, high evaporation, high water table, and the presence of soluble salts in the soil co-occur and work hand in hand to augment salt build-up.

In poorly drained soils, where the groundwater table is 3 m or less from the surface of the soil, water is unable to leach down, and instead rises to the surface by *capillary action*. Capillary action is the natural upward movement of water between soil particles. In hot and dry region, this water leaves the surface of the soil through evaporation. Since groundwater contains naturally dissolved salts, the water evaporates leaving salts behind. The phenomenon repeats constantly, and over time salts concentrate until they reach levels in the root zone that are detrimental to plants.

A similar process occurs in semi-arid drylands where the use of irrigation water is unavoidable. The evaporation of irrigated water leaves natural salts to accumulate on the surface of the soil. Due to the lack of adequate precipitation in arid regions of the world, the accumulated salts are never able to leave the soil through leaching. The build-up of salts can lead to plant toxicity in extreme situation.

6.4 Desertification, Causes and Implications

Desertification is arguably the world's most threatening form of soil degradation that affects over one billion people worldwide, many of them among the poorest in the world.

Desertification is not necessarily the expansion of existing deserts; rather it is the degradation and deterioration of fertile arable land, caused chiefly by overgrazing, overcultivation, deforestation, and poor irrigation.

Desertification occurs on all continents of the world except Antarctica, but chiefly impacts the world's drylands. These include arid, semi-arid, and dry sub-humid regions where potential evapotranspiration often exceeds precipitation, and vegetation cover is already sparse. With excessive pressures of agriculture, deforestation, and overgrazing, the natural vegetation cover can be reduced or completely eliminated, resulting in desert-like conditions. Desertification severely decreases the productive capacity of the land, which leads to a decline in agricultural productivity, food and water scarcity, malnutrition, poverty, and ultimately mass migration out of degraded regions.

In this section, we will look at the natural and anthropogenic causes that reinforce one another to reduce fertility and biological productivity of the soil.

Natural Factors that reinforce Desertification

The soils of arid lands are naturally characterised by shallow depths, insignificant organic content, negligible leaching capacity, absence of structure, high salinity, and low fertility. In arid regions, a low precipitation regime means that the land can only support and carry sparse vegetation cover. As a result, only a thin organic layer accumulates by the slow decomposition of plant remains. Soluble salts and sediments leach to shallow depths or remain at the surface due to the low precipitation regime. Violent dust storms and aggressive thunderstorms cause intensive land erosion and carry away much of the topsoil containing the nutrients and organic matter, leaving the soil even more infertile and unproductive.

Overgrazing

Overgrazing is the single largest and most devastating cause of desertification in arid lands. Livestock are the main source of income and style of life in many developing countries. Domestic stocks are widely diverse and consist of camels, donkeys, horses, cows, sheep and goat.

In many arid regions, the forage and overgrazing of livestock causes a chain of degradation, critically reducing vegetation cover and soil fertility, as well as increasing erosion and chance of flooding. Domestic animals rapidly clear vegetation, placing stress on a land that already has a low vegetation cover. They also move in large groups and have sharp hooves that easily break up the soil, leaving it susceptible to erosion. Erosion



Figure 6.41: Goats feeding on acacia shrub. Overgrazing accounts for over one-third of the world's total of degraded drylands, or nearly 700 million hectares.

Source: FAO Photofile, 1997

decreases fertile organic content of the soil. The lack of organic matter can lead to desertification through reduced nutrient availability for plant growth.

Grazing and trampling causes compacting of the soil and degrading of the structure. The result is decreased soil permeability and plugging of pores which reduce the ability of water to penetrate the soil by infiltration and percolation. Runoff occurs when rainfall intensity exceeds the infiltration capacity of the top-soil. Soil moisture is decreased due to decreased soil organic matter and erosion is intensified because of livestock action. Water erosion may also carry sediments to streams, causing flooding and accumulation of salts.

Overall, degradation by intense livestock action usually takes between 5-8 years and has devastating results. Figure 6.21 summarized the many interrelated ways in which grazing induces desertification.

Deforestation by Firewood Gathering

In many developing parts of the world – which sometimes coincides with the world's drylands – much of the cooking is done on wood fire. Often, women and girls spend a long part of the day collecting and removing vegetation for domestic use. The removal of vegetation leaves the soil nude of its protective cover. Lack of shade encourages evaporation of moisture. Land is prone to wind and water erosion that remove the already minuscule organic content of the soil. Eventually, the soil is left permanently dessertified and unable to recover.



Figure 6.42: Women collecting firewood for cooking in Mali.
Source: Global Issues in Africa, 2005

Intense and Improper Agricultural Practices

Arid lands have a low carrying capacity and can only maintain a low vegetation cover. Therefore a rapidly rising world population placed a great stress on lands that cannot sustain intense agriculture.

When land is cleared and tilled, much of the natural vegetation is removed in anticipation for agriculture. The soil is suddenly bare and exposed to erosive forces such as intense wind and thunderstorms that occur rather frequently in arid regions. Substantial quantities of fertile topsoil and organic sediments are removed. The outcome is a considerable decrease in fertility, water-holding capacity, and loss of structural aggregation. With minimal moisture and nutrient content, the soil loses any ability to support vegetative growth. This ultimately leads to the creation of deserts.

Mismanagement of Irrigation

Proper irrigation is one of the biggest challenges in arid lands where a moisture deficiency makes it impossible for farming to occur without artificial irrigation. However, irrigation in arid lands can further enhance desertification through salinization and alkalinization.

Salinization occurs when irrigation water evaporates quickly, leaving natural salts (eg. chlorides, sulphates, and carbonates) at the surface of the soil. Over a long time, excessive quantities of salts accumulate at or near the soil surface making it increasingly difficult for plants to extract water from the soil. In addition to reduction or complete disappearance of vegetation, salinization also gives rise to compacted soil structure, decreased permeability and porosity, decreased biological activity, and unfavourable changes in pH.

Alkalinization is a similar process, where the accumulation of sodium ions causes the disintegration of soil aggregates, resulting in a weakened soil structure. Poor soil structure generally leads to decreased porosity and aeration, reduced infiltration, oxygen deficiency, and increased runoff and erosion.

The final result is a reduced capacity of the soil to support vegetation and crops.

6.5 Soil Acidification

Acidification is a major land degradation issue. It is a natural process that is aggravated by mismanaged agricultural practices. Soil acidification is a decrease in the pH of the soil beyond those ranges tolerable by plants and soil organisms. When the pH of soil declines to levels far from ideal, plants may experience deficiencies in essential nutrients such as molybdenum, boron, calcium, magnesium and potassium, while toxic elements such as aluminium, manganese, and iron become abundant in dangerous quantities. Soil acidification can be caused by any number of reasons.

As you already know, the soil pH is reflective of the minerals that constituted the original parent material from which the soils were formed. Soils of granitic and igneous origins with copious quantities of silica generally have a natural tendency to form acidic soils. Silica reacts to form silicic acid, which decreases the pH of the soil. The soil acidity is also reflective of the vegetation that grows on it. Coniferous trees such as pine, spruce, and fir have litter that produce acid soil.

By far the most common causes of soil acidification is attributed to high rainfall and excessive use of ammonium-based fertilizers. While acid rain is one contributor to soil acidification, high quantities of rainfall also cause the leaching of soluble basic elements such as calcium and magnesium and their replacement by such elements as aluminium and hydrogen. Nitrogen-based fertilizers also impose a decalcifying and acidifying effect on the soil. When agricultural crops and products are harvested and removed from the land, alkaline elements are permanently removed. This is the means by which agriculture exacerbates the rate of soil acidification.

When acidification occurs, uptake of heavy metal contaminants increases and may cause toxicity in plants, whereas the concentration of necessary nutrients decreases. The result is reduced crop yield and vegetation cover, leading to accelerated runoff and erosion. Soil microorganisms would also be negatively impacted by toxicities, preventing the continued recycling of nutrients.

Soil acidification causes the overall value of the land to decrease.

6.6 Soil Compaction

Soil compaction is the increase in bulk density of the soil that occurs when soil particles are packed closer together, reducing the pore space between them. Compaction is a serious problem because it reduced the productive capacity of the land.

Soil compaction is induced in two ways. When heavy agricultural machinery is used to till the soil and harvest crops, the soil becomes compressed under the pressure of the machine's heavy weight. This is called mechanical compaction. Compaction also occurs when grazing animals roam the land in large packs, their hooves pushing the soil particles tighter together.

Soil compaction is more likely to occur when soils are wet and has several implications. When the porosity of the soil is reduced, infiltration rates decline, causing accelerated runoff and erosion. Also, when soils are compacted, root growth becomes restricted, causing a reduction in water and nutrient uptake, and eventually reduced growth and yield. This is bad news for farmers, who depend heavily on the economic capacity of the land. The population and diversity of microorganisms and larger organisms is also adversely affected by the lack of air and water circulation. Decreases soil microorganism activity leads to decreased organic matter decomposition, and diminishes the availability of nutrients.

Figure 6.51: Soil compaction occurs when the pressure of overlying heavy farming machinery causes soils to become denser.

Source: Omnitrac: Track vs. Tires



6.7 Soil Contamination

Soil pollution is associated with serious and catastrophic environmental impacts. Soil contamination results when hazardous chemicals are spilled or buried directly into the soil, or when they migrate from elsewhere with air and water and deposit in the soil. Common soil contaminants include pesticides and PCBs, oil, road salt, and elements such as lead, fluorine, or cadmium. Contaminants are introduced to the soil through disintegration of underground storage tanks, addition of municipal sewage sludge, discharge of industrial waste, leaching of landfills, accidental spills, and smelter fallouts.

The widespread use and disposal of harmful chemicals means that they can easily enter the food chain and damage the health of plant and animal species. Pollutants in the soil are taken up initially by plants and burrowing soil organisms, where they accumulate in the body without breaking up. These plants and animals are consumed in large number by organisms higher in the food chain. As a result, the pollutants build up in progressively higher concentrations in organisms of higher trophic levels. This process is called *bio-magnification*. Due to bio-magnification, the impacts of soil toxins are most visible in organisms at the top of the food chain. In the long term, this accumulation of toxins can cause sickness, disease, reproductive failure, genetic defects, and in extreme cases, death.

A common example of soil contamination is the use of sewage sludge as a fertilizer. Though sewage is a rich source of the essential nutrients phosphorus and nitrogen, it is often laced with high concentrations of contaminants such as nickel, arsenic, zinc, and cadmium. Repeated applications of sewage sludge to soil can cause the buildup of these toxins in the ecosystem with bio-magnification in humans and other animals high in the food chain.

Another common source of soil contamination is road salt. Though essential for the removal of snow, salt concentrations can build up along roadways causing stress and even death to plants and other vegetation.

Most symptoms of soil contamination only become visible in over the long term as pollutants steadily build up in an area. However, some sources of pollution are extremely concentrated, causing immediate complications.

Oil leaks, for example, occur when underground storage tanks deteriorate over time, releasing chemicals to the soil. These chemicals can be carried vertically and laterally throughout the soil profile, contaminating underground and surface drinking water sources.

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