Chapter 2

Soil Degradation and Land Use Change: Challenge and Implications

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Abstract

Soil degradation, characterized by the deterioration and loss of soil functions, has been increasingly severe on a global scale in recent years, posing a significant risk to both Farming output and land-based ecosystems. It delineates the fundamental processes and factors accountable for soil deterioration, elucidates the factor and causal relationships, and distinguishes among naturally occurring as well as human-induced adverse impacts. Human activity and the resulting alterations in land use stand as the foremost catalyst for the hastened erosion of soil. This has extensive implications for the cycling of nutrients and carbon, land productivity, and, consequently, socio-economic conditions across the globe. This underscores the necessity of addressing these issues through a comprehensive approach that encompasses scientific research, sustainable land management practices, and policy interventions. Conservation techniques such as afforestation, reforestation, crop rotation, and reduced tillage have proven effective in counteracting soil degradation, while responsible land use planning and the implementation of zoning regulations are imperative for minimizing adverse repercussions.

Keywords: Afforestation, erosion, land use change, soil degradation, sustainable

I. INTRODUCTION

Soil degradation stands as a paramount environmental concern in numerous nations. According to the FAO (1993), Soil degradation comprises geological, climatic, biological, and anthropogenic factors that, together, undermine the physical, chemical, and biological qualities of soil. This poses a threat to biodiversity, land utilization, and, ultimately, the survival of human communities. Lal (1997) underscores that soil degradation results in a deterioration of soil quality, perpetually reducing productivity. In India, Bhattacharyya *et al*. (2015) estimate that soil degradation affects a staggering 147 million hectares, an alarming situation given that the country sustains 18% of the world's human population and 15% of the global animal population on a mere 2.4% of the Earth's landmass.

Soil degradation poses a substantial challenge, hindering efforts to feed a growing global population on diminishing land of deteriorating quality. This leads to food insecurity, reduced agricultural incomes, and economic sluggishness. Moreover, soil degradation triggers secondary issues such as sedimentation, carbon emissions contributing to climate change, diminished watershed function, and alterations to natural habitats that result in genetic stock loss and biodiversity decline (Scherr, 1999). Poverty exacerbates the effects of soil degradation, causing more severe repercussions on soils managed for subsistence farming with no external inputs than on those managed for commercial agriculture with science-based interventions.

The reasons behind this degradation can be attributed to a dual nature, arising from both natural and human influences. Natural factors encompass earth-shattering events like earthquakes, weather events such as tsunamis, droughts, and wildfires, as well as geological phenomena like avalanches, landslides, volcanic eruptions, and floods. On the other hand, anthropogenic soil deterioration arises from practices like deforestation, improper handling of industrial waste, overgrazing, careless forest management, urban expansion, and industrial growth. Insufficient agricultural methods, such as excessive soil cultivation, the utilization of heavy machinery, imbalanced application of synthetic fertilizers, subpar irrigation methods, overuse of pesticides, insufficient organic matter input, and inadequate crop rotation planning, also make substantial contributions.

II. PROCESS OF SOIL DEGRADATION

Soil degradation results from depleting activities and their interplay with natural surroundings. The processes involved in soil degradation encompass chemical, physical, and biological actions and interactions that impact a soil's ability to self-regulate and its overall productivity. Here are the key processes involved in soil degradation:

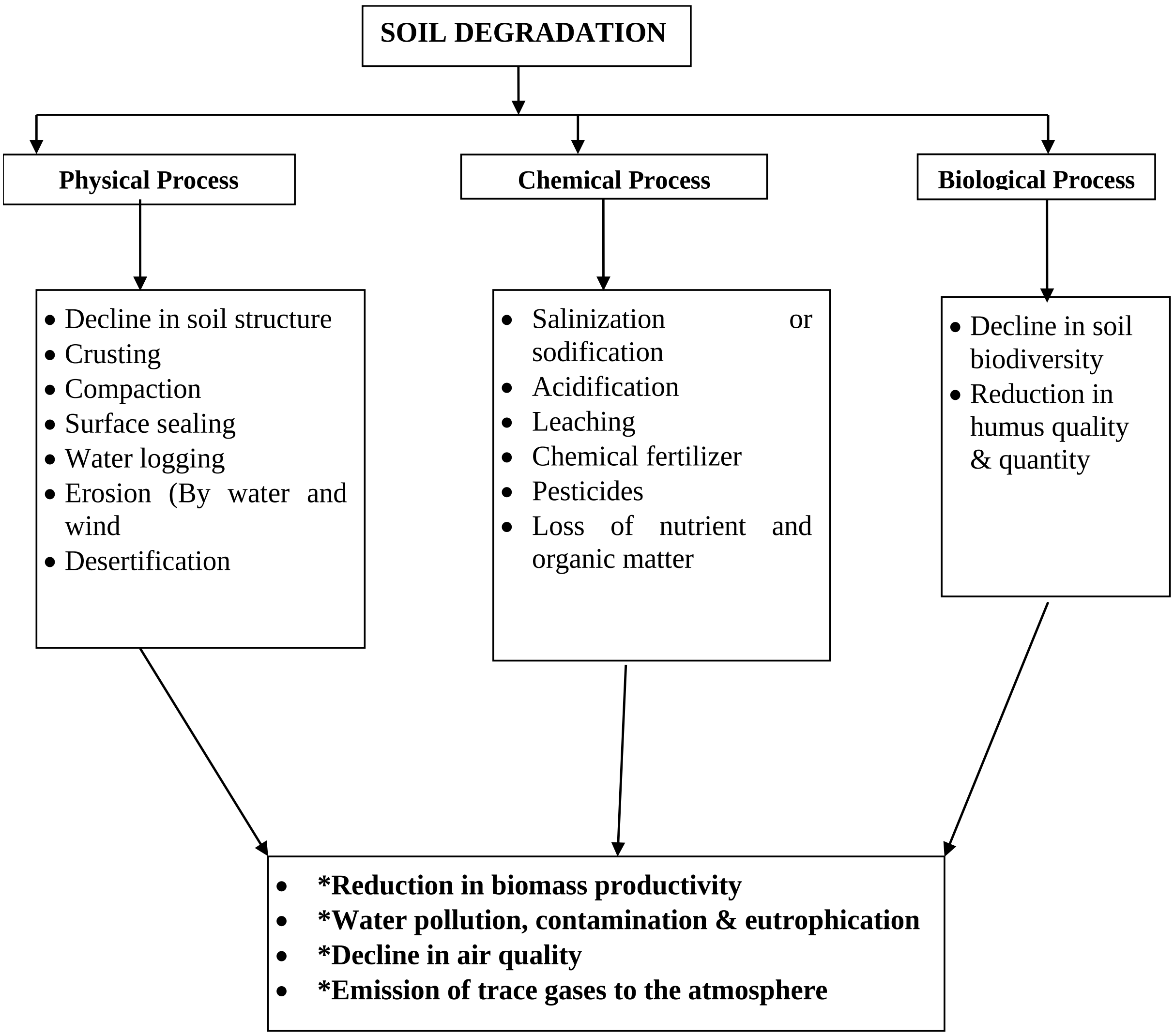

Figure 1: Soil degradation processes

1. Chemical Degradation

This relates to the buildup of noxious substances and chemical processes that disturb the essential chemical properties required to regulate the soil's life-sustaining functions (Logan, 1990).

According to Suraj *et al.* (2001), any alteration in these chemical properties can directly and indirectly harm the chemical fertility of soils. Chemically degraded soils exhibit elevated levels of harmful chemicals that disrupt critical soil life processes. Furthermore, these harmful substances can disrupt nutrient availability, hinder nutrient uptake, and impede the movement of essential nutrient elements.

A. Salinization and Sodification

Salinization, which involves the accumulation of water-soluble salts, including sodium, potassium, magnesium, calcium, sulfate, carbonate, and bicarbonate ions, either on the soil surface or in close proximity to it, specifically refers to the excessive presence of exchangeable sodium ions (Na^{+}) in the soil, rendering it completely unproductive (Kavvadias, 2014).

B. Acidification

The intensive cultivation of upland areas without the incorporation of essential nutrients and organic material to the soil has been identified as a contributor to the prevalent occurrence of acidic upland soils (NAP, 2004). Acidification involves an alteration in the chemical composition of the soil, potentially leading to the release of harmful metals (Nagle, 2006). This acidification has detrimental effects on the soil ecosystem and can harm plant growth. Additionally, it alters the chemical composition of soil water. Soil acidification can result from a decrease in pH levels or from the deposition of acidic substances in the environment.

C. Chemical Fertilizer

Inorganic fertilizers primarily consist of compounds like phosphates, nitrates, ammonium, and potassium salts. These fertilizers also contain a significant amount of heavy metals, including mercury, cadmium, hassium, lead, copper, nickel, and zinc. These elements are extensively recorded as factors that contribute to soil degradation. The application of fertilizers, particularly industrial ones like sodium nitrate, ammonium nitrate, potassium chloride, potassium sulphate, and ammonium chloride, is known to deteriorate soil structure (Savci, 2012). Moreover, the ongoing application of nitrogen-based fertilizers, which generate acidity, results in a reduction in soil pH (Moebius-Clune et al., 2011).

D. Pesticides

Pesticides have played a significant role in modern agriculture, contributing to food security. However, it's important to note that these chemicals can have adverse effects on soil microorganisms, which have a pivotal role in preserving soil fertility (Nawab et al., 2002). This highlights the intricate relationship between pesticides and soil fertility. When pesticides harm soil macroflora and microfauna, they can disrupt the delicate balance of the soil ecosystem, potentially impairing its ability to support healthy plant growth and sustainable agriculture.

E. Loss of Nutrients and Organic Matter

The swift decline in organic matter and nutrients in the topsoil primarily results from the clearance of natural vegetation. However, other substantial factors contributing to this loss encompass biomass burning, shifting cultivation, and erosion. Human-induced soil nutrient depletion refers to a process in which the nutrient reserves in the soil gradually diminish due to continuous nutrient extraction through agricultural practices without sufficient nutrient replenishment. This depletion is further intensified by accelerated soil erosion and leaching (Tan et al., 2005).

2. Physical Degradation

Physical deterioration represents a significant surface of soil degradation, and it encompasses several methods by which soils deteriorate. These methods include:

- **Surface Sealing, Surface Crusting, Hardsetting, and Compaction (Pc):** These processes involve the formation of a hardened surface layer on the soil, which hinders water infiltration and root penetration, leading to reduced soil quality.

- **Waterlogging (Pw):** Waterlogging occurs when soil becomes saturated with water, impairing aeration and root function. This can result in soil degradation as well.

- **Lowering of Water Table (Pa):** The decline of the water table level can negatively affect soil quality, particularly in areas dependent on groundwater for maintaining soil moisture.

- **Subsidence of Organic Soils (Ps):** This refers to the gradual sinking or settling of soils rich in organic matter, often caused by factors like drainage or decomposition. It can lead to the loss of valuable topsoil.

  Desertification, which is a type of physical degradation, has become a notable concern in arid and semi-arid regions.

A. Soil Erosion: Soil erosion and degradation are interrelated, with erosion often following declining soil quality and structure. It physically removes soil both vertically and horizontally, degrading its quality. Erosion involves detachment, transport, and deposition of soil, driven by factors like water, wind, and gravity (Noori et al., 2018). Various factors, including topography, land-use changes, rainfall patterns, and population demographics, affect erosion rates. These factors collectively determine the effect of erosion on landscapes and soil quality.

- **Soil Sealing**: Soil sealing renders affected soils unsuitable for various uses, including agriculture and forestry. It also severely hinders or even completely prevents the natural soil functions crucial for ecological health. Moreover, soil sealing can impact neighboring soils by altering water flow patterns and fragmenting habitats, leading to broader ecological consequences.

  Agassi et al. (1981) identified two complementary mechanisms responsible for the formation of soil seals:

- **Physical Breakdown of Soil Aggregates:** This occurs when soil aggregates break apart due to wetting and the effect of raindrops.

- **Physicochemical Dispersion of Clay Particles:** Clay particles disperse as a result of physicochemical reactions. The scattered particles obstruct the pores in the soil, resulting in the creation of a barrier with reduced permeability. As a result, the top layer of soil becomes resistant to the passage of both water and plant roots.

B. Surface Crusting: Surface crust formation includes two key processes:

- **Physical Action:** This encompasses the breaking apart of soil aggregates and the compression of soil particles caused by the force of raindrops.

- **Physicochemical Action:** This mechanism entails the scattering of soil aggregates and the migration of soil particles, potentially obstructing conducting pores and leading to reduced permeability in the uppermost soil layer (Cai *et al*., 1998).

These processes collectively contribute to the development of surface crusts, which can significantly affect soil properties, plant growth, and water infiltration.

C. **Hardsetting:** It encompasses multiple soil layers, leading to the development of a hard and compacted soil structure over a more significant depth. This can have detrimental effects on soil quality, water infiltration, and plant root growth, making it an important consideration in soil management and agricultural practices.

D. **Soil Compaction:** Compaction alters soil structure, increases bulk density, raises penetrometer resistance, reduces aeration, limits water infiltration, and decreases hydraulic conductivity. These soil property changes hinder crop growth by impeding root growth, disrupting root architecture, and reducing root distribution (Keller et al., 2019).

E. **Waterlogging:** Waterlogging occurs when soil becomes saturated with water for an extended period, often due to a rising groundwater table (Michael and Ojha, 2006). This condition has detrimental effects on soil and land, including reduced aeration, conversion of arable land into wasteland, and the development of soil salinity.

F. **Desertification:** Desertification is a phenomenon marked by the progression, enlargement, or deterioration of land and vegetation degradation. It is especially prevalent in areas with low population density, unfavorable ecological conditions, and insufficient resource management practices (Zhou et al., 2003).

The consequences of desertification are including:

- **Reduce Biological Productivity:** Desertification diminishes the ability of land to support plant and animal life, resulting in a decline in biological productivity.

- **Decreased Carrying Capacity:** Land affected by desertification becomes less capable of sustaining human and animal populations, which can lead to displacement and food security challenges.

- **Ecological Deterioration:** Desertification exacerbates ecological degradation, impacting the overall health of ecosystems and biodiversity.

3. Biological Degradation

The diminishing levels of organic matter, a decrease in the activity and diversity of soil fauna and flora, and shifts in biological processes from positive to negative trends represent worrisome developments in soil health. Soil microorganisms, which are responsible for recycling both organic and inorganic materials, play a crucial role in the ongoing rejuvenation of soil (Gömöryová *et al.*, 2011).

Biological crusts are complex ecosystems that consist of a variety of living organisms. These include algae, cyanobacteria (commonly known as blue-green algae), bacteria, lichens, mosses, liverworts, and fungi, which inhabit the soil surface or dwell just beneath it. These organisms in the soil are crucial for nutrient cycling, breaking down organic matter, detoxifying pollutants, and suppressing harmful microorganisms. Additionally, they influence soil porosity and can either enhance or reduce infiltration rates compared to soils lacking biological crusts (Belnap *et al.*, 2001).

III. CONSEQUENCES OF SOIL DEGRADATION

1. Reduction in Plant Population

Grassland degradation is a global concern with significant Detrimental environmental consequences (Crossman *et al.*, 2018). Overgrazing decreased vegetation coverage and reduced plant biomass, which in turn has adverse effects on various soil physiochemical properties. These properties include soil porosity, BD, soil water content, soil organic carbon, and soil total nitrogen (Zhang *et al.*, 2015).

2. Increasing Flooding/Runoff

Floods are temporary inundations of land caused by surface waters escaping from their usual confines or by heavy precipitation (Munich, 1997). Soil erosion contributes to increased flooding, not only because it removes vegetation that once captured rainwater and slowed its flow into rivers but also due to the rising riverbed (Wang *et al.*, 2015). Tillage practices that lead to compaction of topsoil reduce its ability to absorb water and increase the probability of surface runoff occurring during intense rainfall events (Byrd *et al.*, 2002).

3. Aridity or Drought

Drought exerts detrimental effects on agriculture, and its occurrence and severity are on the rise in many regions worldwide. This trend can be attributed to both natural factors and human-induced climate changes (Trenberth *et al*., 2014), with soil degradation playing a significant role. Consequently, the factors contributing to declining soil quality, such as overgrazing, inadequate tillage practices, and deforestation, are also the primary drivers of desertification, characterized by arid conditions and drought.

4. Decline Soil Quality

Soil degradation involves deterioration in soil quality, resulting in a decrease in the functionality and services provided by ecosystems. Fertilizer application without adhering to soil testing recommendations can have adverse consequences, including soil degradation, nutrient imbalances, the disruption of soil structure, and an increase in bulk density (Çevre *et al*., 2004).

5. Pollution and Clogging of Waterways

Soil degradation commonly leads to significant alterations in the natural landscape, changing its physical composition over time. The sedimentation process that ensues can block waterways, ultimately causing water scarcity. Agricultural soils can accumulate high levels of toxic elements like arsenic (As) and copper (Cu) and organic contaminants due to the use of agrochemicals and sewage sludge (Arunakumara *et al*., 2013).

IV. CONTROL MEASURE

Controlling soil degradation involves implementing a combination of preventive measures and sustainable land management practices. Here are some key control measures:

1. Managing Soil Erosion

Soil conservation techniques, including methods like contour ploughing, bunding, the utilization of strips and terraces, have the potential to reduce erosion and mitigate the rapid flow of runoff water. Additionally, employing mechanical strategies, such as physical barricades like embankments and windbreaks, as well as implementing vegetative cover, along with responsible soil management, constitute crucial approaches for managing soil erosion (Singh *et al*., 2014).

2. Water Harvesting

Implementing water conservation strategies is crucial for effectively addressing soil erosion in sloped areas and retaining as much rainfall as possible. These strategies also help in safely redirecting excess runoff from highland areas to the foothills of India. Gaining insights into the interplay between water, soil, and vegetation is crucial for improving assessments of soil degradation (Ouedraogo *et al.*, 2016).

3. Sub-soiling

Sub-soiling, a conservation tillage technique, and offers an effective means to disrupt the plough layer or compacted soil layer without completely overturning the subsoil (Choudhary *et al.*, 2013). This method proves particularly suitable for arid regions. Sub-soiling achieves soil loosening by fracturing the subsurface layers, resulting in a reduction in soil BD and an enhancement in soil aeration. Consequently, this process improves the ability of the soil to retain water (Qin *et al*., 2008).

4. Integrated Nutrient Management and Organic Manuring

Proper and combined utilization of plant nutrients through both organic and inorganic sources offers effective solutions to address the declining health and productivity of soils (Urmi *et al.*, 2022). The incorporation and efficient management of crop waste residues, FYM and green manure have become increasingly vital components of environmentally responsible and sustainable agricultural practices (Timsina and Connor, 2001).

5. Reclamation of soil

These approaches may involve activities like incorporating plant residues into degraded soil and implementing improved range management practices. To ameliorate acidic soils, liming stands out as the most effective practice. Lime acts to raise the pH level of the soil, thereby improving the accessibility of vital plant nutrients while decreasing the toxicity of elements like iron and aluminum (Sharma *et al.*, 2005). For the management of saline soils, various techniques come into play, including tillage, irrigation, and leaching. Inversion tillage, in particular, has the potential to reduce the accumulation of soluble salts in the root zone when compared to zero tillage practices (Wilson *et al.*, 2000).

6. Enhancing Input Use Efficiency through Irrigation Management

To attain this enhancement in method and system performance, it's essential to take into account various factors, particularly those that influence hydraulic processes, water infiltration, and the evenness of water distribution throughout the entire field (Pereira, 1999). It also enhances the transpiration component of evapo-transpiration, reducing water loss and consequently improving crop productivity while mitigating soil degradation.

7. Reforestation

The presence of trees has a positive impact on physico-chemical and microbial biomass parameters, primarily by storing higher levels of Soil Organic Carbon (Ramesh *et al.,* 2010). Trees within agroforestry systems serve two vital functions: (i) their fine root systems stabilize the soil, reducing its vulnerability to erosion, and (ii) the plant stems slow down runoff, promoting sedimentation.

8. Conservation Tillage/Agriculture

Conservation agriculture or tillage encompasses a set of scientifically grounded principles that are progressively being embraced on a global scale. These principles include:

- Reducing soil surface disturbance through the utilization of no- or low-tillage techniques.
- Maintaining continuous soil surface coverage through methods such as retaining crop residues, mulching, or cultivating cover crops.
- Utilizing crop sequences or rotations that incorporate agroforestry within spatial and temporal frameworks.
- Implementing controlled traffic patterns.

  Conservation agriculture or tillage has the capacity to mitigate sub-surface compaction and improve the least limiting water range (Mishra *et al.,* 2015).

V. LAND USE CHANGE

Land use change refers to the modification of the purpose or function of a particular area of land. It's widely recognized that alterations in land use and management can have profound effects on soil properties and functions. The conversion of forested land into pastures or cropland, for example, can significantly impact soil properties. The magnitude of this impact varies based on several factors:

- The manner in which the forest is cleared or harvested.
- The nature, duration, and intensity of subsequent agricultural and pastoral practices.
- The underlying pedological (related to soil), morphological (related to landforms), and climatic conditions.

These factors collectively influence the severity of soil erosion, nutrient uptake, physical and biological degradation of soils.

Land use changes often follow a predictable pattern, progressing from the restoration of natural vegetation to boundary clearing, subsistence agriculture, small-scale farming, and ultimately to intensive agriculture, urban development, and protected recreational lands (Bonan *et al.*, 2005). These changes in land use frequently lead to soil degradation, especially when heavy machinery is used. Intensified grazing can also bring about significant alterations to soil properties (Carroll *et al.,* 2004). To evaluate the impact of these land use changes on soil degradation or restoration, it is possible to assess specific soil characteristics, including levels of organic carbon and nutrients (Wang and Gong, 1998). Generally, the conversion of grasslands to cultivation results in the loss of SOC and nutrients, signaling land deterioration.

In summary, the effect of land use change on soil degradation is contingent on the specific changes and practices involved. Sustainable land management practices that focus on reducing erosion, preserving organic matter, and minimizing chemical inputs are essential for mitigating soil degradation and maintaining soil health in the face of evolving land uses.

VI. CONCLUSION

Soil degradation and land use change are interconnected challenges that have significant implications for our environment, food security, and overall sustainability. Soil degradation, attributed to factors such as erosion, compaction, nutrient depletion, and contamination, presents a significant challenge to the productivity of both agricultural areas and natural ecosystems. Land use change, driven by urbanization, agriculture land expansion, and deforestation, alters the landscape and exacerbates soil degradation. Addressing these issues requires a multifaceted approach that combines scientific research, sustainable land management practices, and policy interventions. Conservation measures such as afforestation, reforestation, crop rotation, and reduced tillage can help mitigate soil degradation. Additionally, responsible land use planning, urban development, and zoning regulations can minimize the negative effects of land use change on soil quality.

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