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Impact of Land Use Changes on Soil Properties and Functionality

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Abstract

Land use change involves the transformation of natural landscapes through human activities, altering their physical and ecological characteristics. This process includes converting natural environments like forests into agricultural or urban areas, which can lead to soil degradation through mechanisms such as surface runoff, pollution, and erosion. Despite these challenges, agricultural and woodland areas within urban and peri-urban regions continue to provide essential services, including food production, water supply, and climate regulation. The drivers of land use change are complex and interconnected, involving economic development, population growth, technological advancements, and policy and governance factors. Analysis of land use from 2001 to 2021 reveals significant shifts: vegetation and water-covered areas have decreased, while settlements, arid lands, and agricultural areas have expanded. Land use change impacts soil functionality by degrading soil quality and reducing essential ecosystem services. Factors such as decreased soil organic matter, nutrient depletion, increased erosion, altered soil structure, and changes in soil pH highlight the need for sustainable land use policies and restoration practices. These impacts are evident in soil composition, nutrient availability, porosity, water holding capacity, and overall soil health. Groundwater quality also suffers from poor land management, with issues such as salinization, nitrate pollution, contamination by agricultural chemicals, depletion, and seawater intrusion. Soil biodiversity is threatened by habitat loss, pollution, and soil

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degradation, emphasizing the need for sustainable practices to preserve biodiversity and soil health. In conclusion, land use change significantly affects soil properties and functionality, leading to reduced soil fertility, increased erosion, and overall degradation. Effective land management and restoration practices are vital for maintaining soil productivity and ensuring the sustainability of natural resources and ecosystems.

Key Words: Land, Quality, Soil Properties and Functionality

Introduction:

Land use change refers to the transformation of natural landscapes by human activities, altering their physical characteristics and ecological functions. This process includes the conversion of natural environments, such as forests, into agricultural land or urban areas. Land-use change often leads to soil degradation through surface runoff, pollution, and erosion. However, in urban and peri-urban regions, areas dedicated to agriculture and woodlands still play crucial roles in providing essential services like food production, water supply, and climate regulation.

Land-use change has a significant impact on soil properties and soil organic carbon levels, particularly in intensively managed areas like croplands and vineyards. Practices such as tillage, pesticide application, and the use of fertilizers contribute to the degradation of soil quality. As a global issue, land-use change (LUC) affects agriculture, soil properties, ecosystems, and the broader environment, including atmospheric composition (Hasan *et al*., 2020; Han and Zhu, 2020; Newbold *et al*., 2015). Intensively cultivated regions may see a reduction in the soil's ability to provide ecosystem services, such as carbon sequestration and flood mitigation.

Key dynamic soil properties such as soil organic matter (SOM), cation exchange capacity (CEC), total nitrogen (TN), pH, and texture are sensitive to land use practices. These properties provide valuable insights into important soil processes like nutrient cycling, decomposition, and SOM formation, which are critical for maintaining soil productivity (Mandal *et al*., 2007).

Causes of Land Use Change

Land use change is driven by a range of complex, interconnected factors, including human, economic, and environmental influences. A deeper understanding of these causes highlights the multifaceted nature of such changes:

- **Economic Development**: Activities like mining, agriculture, and construction often require the transformation of natural habitats into industrial, agricultural, or urban spaces.
- **Population Growth**: As populations expand, there is an increasing demand for housing, food, and infrastructure, which drives the conversion of natural landscapes into urban or agricultural areas.
- **Technological Advancement**: Innovations in farming, construction, and energy production can intensify land use, frequently at the expense of natural ecosystems.
- **Policy and Governance**: Government policies, zoning regulations, and property rights play a critical role in determining how land is used and the extent of land use change.

Land Use Changes (2001–2021)

An analysis of land use from 2001 to 2021, based on classified images, shows significant shifts. Vegetation and water-covered areas have decreased, while settlements, arid lands, and agricultural areas have expanded. Specifically:

- Water-bodies decreased by **75.93%**.
- Vegetation-covered land decreased by **87.77%**.
- Agricultural land increased from **838.88 km²** to **1254.25 km²**.
- Settlement areas grew from **63.29 km²** to **346.12 km²**.
- Arid land expanded from **465.25 km²** to **584.96 km²**.

Much of the previously vegetated land has been converted for agricultural and settlement use, driven largely by urban expansion and population growth.

Impact of Land Use Change on Soil Properties and Functionality

Land-use change, particularly through deforestation and soil disturbance, is a major contributor to soil quality degradation and greenhouse gas emissions. It affects soil's physical and chemical properties, leading to diminished soil quality and the loss of carbon stocks. Various global studies have explored land-use change management strategies that can restore soil carbon and microbial biomass. However, such analyses in the Indian context remain limited.

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The overall impact of land-use and land-cover changes has led to soil degradation, emphasizing the need for appropriate land use policies and restoration practices to preserve soil productivity.

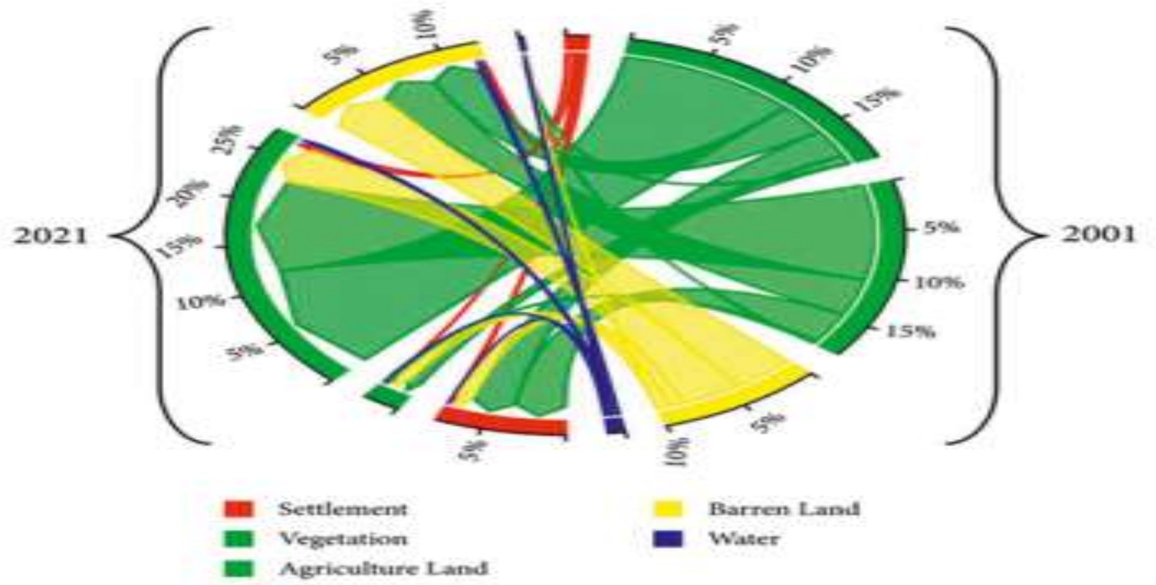

Fig: No-1 Impact of Land Use Change on Soil Properties and Functionality.

Impact of Land Use Change on Soil Properties:

Land use change significantly affects various soil properties in multiple ways, including:

Soil Composition:

Soil is a complex material composed of five key components:

Minerals: Derived from the breakdown of rocks, minerals are classified into three size groups—sand, silt, and clay. The relative amounts of these particles determine the soil's texture.

Organic Matter: Composed of decayed plant and animal matter, as well as microbial tissues, this component is crucial for soil fertility.

Water: Absorbed from the atmosphere and soil reactions, water plays an essential role in supporting plant life.

Air: Soil air is necessary for the respiration of soil organisms and plant roots, and it is supplied through both atmospheric exchange and soil reactions.

Living Organisms: Soil hosts a wide variety of life, from large organisms like earthworms and insects to microscopic bacteria and fungi.

Soil pH

Soil pH, which affects nutrient availability and plant growth, is strongly influenced by land use and management practices. For instance:

Natural forests typically have a slightly higher pH compared to cultivated and grazing lands.

Soils under orchards and block plantations tend to have lower pH compared to agricultural crops or silviagri systems. This is likely due to the accumulation of organic litter, which becomes acidic as it decomposes. Over time, converting forest or grassland to cropland can cause a significant drop in soil pH. This change is driven by the loss of organic matter, the depletion of soil minerals during crop harvests, and surface erosion. Additionally, the use of nitrogen and sulfur-based fertilizers can further lower pH levels, making soils more acidic.

Soil Nutrient Availability

Micronutrients in the soil are most readily available at the surface and their concentration decreases with depth. Higher cation exchange capacity (CEC), which is crucial for nutrient retention, is commonly observed in silviagri systems due to the presence of organic matter and specific types of clay particles. The amount and type of clay significantly influence CEC across various land use systems (Tufa *et al.*, 2019). Conversely, agricultural crops tend to have lower CEC, primarily due to reduced organic matter caused by intensive farming practices (Bhople and Sharma, 2020).

Nutrient availability is closely linked to soil pH, with essential plant nutrients classified as macronutrients and micronutrients based on plant needs. Macronutrients such as nitrogen, calcium, potassium, magnesium, and sulfur are most accessible in soils with a pH of 6.5–8, while micronutrients are typically available in a slightly more acidic range of pH 5–7. Outside of these optimal pH ranges, nutrient availability decreases, potentially limiting plant growth.

Soil Porosity and Water Holding Capacity

Intensive agricultural soils, including vegetable gardens, paddy fields, and tea gardens, tend to have higher porosity and water-holding capacity compared to other land types. Soil porosity the proportion of non-solid space within the total volume of soil is vital for plant growth, as it enables the movement of water, air, and nutrients.

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Land use changes, such as converting grassland or shrubland to cropland, often reduce soil infiltration rates, making the soil less capable of absorbing water. This can negatively affect water availability and plant health over time.

Soil Degradation

Land use changes can accelerate soil degradation, notably through increased soil erosion. Erosion not only strips the land of fertile topsoil but also contributes to pollution by introducing sediment into rivers and streams, harming aquatic ecosystems. Eroded land is also less effective at retaining water, exacerbating flooding risks. Projections of future soil erosion rates rely heavily on models that factor in rainfall erosivity, land use changes, and the impact of policies on soil conservation. Recent developments, such as the Rainfall Erosivity Database at European Scale (REDES), offer valuable insights for predicting future rainfall-related erosion risks under different climate scenarios. Adopting sustainable land use practices is essential to mitigating soil erosion, preventing degradation, and avoiding the loss of valuable land to desertification.

Groundwater Quality

Poor land management and inappropriate land use practices can have lasting impacts on groundwater quality, leading to several chronic issues:

- **Salinization**: Groundwater salinity can increase due to obstructions in drainage systems or salt discharge. Poor irrigation management, which leads to excessive water stagnation, can be a major contributor to this issue.
- **Nitrate Pollution**: Agricultural activities, especially the extensive use of nitrogen-based fertilizers and tillage, can introduce large amounts of nitrates into groundwater, posing health risks and environmental hazards.
- **Contamination by Agricultural Chemicals**: Pesticides and herbicides used in farming can leach into groundwater, depending on their mobility and interaction with soil particles. This contamination poses risks to both human health and aquatic ecosystems.
- **Groundwater Depletion**: Rapid urbanization, increased industrialization, and intensive agricultural activities put significant pressure on groundwater resources, often leading to depletion over time.

- **Soil and Water Salinization**: The expansion of irrigated agricultural areas can result in the salinization of both soil and water, degrading their quality and limiting agricultural productivity.
- **Seawater Intrusion**: In coastal areas, over-extraction of groundwater for irrigation or other uses can lead to seawater intrusion, where saltwater contaminates freshwater aquifers.

Land use changes can influence groundwater quality by altering water demand, recharge rates, and the flow of contaminants into aquifers.

Soil Biodiversity

Land use changes significantly affect soil biodiversity, which includes the variety of plants, animals, and microorganisms within the soil. Sustainable agriculture is critical for preserving soil biodiversity, as soil quality and fertility can rapidly decline due to factors such as intensive cultivation, leaching, and erosion (Kiflu and Beyene, 2013). Key threats to biodiversity from land use changes include:

- **Habitat Loss**: Conversion of natural habitats into agricultural or urban land reduces their size and fragments ecosystems, which can lead to the extinction of species.
- **Pollution**: Excessive use of agrochemicals, such as pesticides, herbicides, and fertilizers, can damage ecosystems by harming pollinators, birds, and aquatic life.
- **Soil Degradation**: Hard surfaces from urbanization reduce rainwater infiltration, which impacts groundwater recharge and disrupts soil health.
- **Noise Pollution**: Urbanization and industrial activities contribute to increased noise levels, affecting both wildlife and human populations.

Impact of Land Use Change on Soil Functionality

Land use change impacts the environment, human health, and the ability to manage soil functionality in several ways:

- **Agricultural Profitability**: As land is converted from agricultural use to residential or industrial purposes, farmers face increased pressure on land availability, leading to reduced profitability. Higher operational and variable costs also contribute to this challenge.

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- **Ecosystem Services**: Changes in land use affect the ecosystem services provided by soil, such as supporting (nutrient cycling), provisioning (food and water), regulating (climate control), and cultural (recreational) services.
- **Management Practices**: Sustainable agricultural practices like cover cropping and reduced tillage can help mitigate the negative impacts of land use changes on soil health.
- **Regional Variations**: The impact of land use change on soil properties and ecosystem services varies by region, depending on climate and geographical factors.

Soil Ecosystems and Climate Change

Land use changes can have direct effects on soil ecosystems, including the biodiversity of organisms that support essential soil functions. These changes can also influence broader environmental processes:

- **Soil Ecosystems**: Land use conversion can disrupt the activities of "ecosystem engineers," such as earthworms and microbes that maintain soil structure and fertility.
- **Climate Change**: Land use changes, such as deforestation and conversion to agriculture, contribute to climate change by reducing carbon sequestration and increasing greenhouse gas emissions.
- **Natural Resources**: Altering land use can deplete valuable natural resources, such as water and fertile soil, which are essential for long-term sustainability.
- **Biodiversity**: Changes in land use can negatively impact biodiversity, causing species loss and reducing ecosystem resilience.
- **Ecological Balance**: Land use changes can disrupt ecological balance and sustainability by altering water cycles, nutrient flows, and habitat structures.

Conclusion:

Land use change, driven by human activities such as agriculture, urbanization, and economic development, has profound impacts on natural landscapes, soil properties, and ecological functions. The conversion of forests and other natural environments into agricultural or urban areas often leads to soil degradation through mechanisms like erosion, pollution, and surface runoff. These changes can reduce soil organic carbon levels and compromise the soil's ability to provide essential ecosystem services, such as carbon sequestration and flood mitigation.

The analysis of land use shifts from 2001 to 2021 highlights significant reductions in vegetation and water bodies, alongside expansions in agricultural, settlement, and arid areas. This transformation has led to notable soil quality issues, including decreased organic matter, altered soil pH, reduced nutrient availability, and increased erosion. These changes not only impact soil productivity but also affect groundwater quality, soil biodiversity, and broader ecosystem functions. Addressing the challenges posed by land use change requires a multifaceted approach that includes sustainable land management practices, restoration of degraded areas, and the implementation of policies that balance development with environmental preservation. Effective strategies must focus on maintaining soil health, protecting biodiversity, and ensuring the long-term sustainability of natural resources. By adopting these measures, we can mitigate the negative effects of land use change and support resilient ecosystems and productive agricultural systems.

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