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# Assessment of Soil Health and Ecosystem Functions Under Diverse Forest Types in the Himalayan Region: A Case Study of Shimla District

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**Abstract:** ***Soil health forms the foundation of forest productivity and ecosystem sustainability by regulating nutrient cycling, carbon sequestration, water retention, and biodiversity. The Himalayan region, particularly Shimla District of Himachal Pradesh, supports diverse forest ecosystems dominated by Deodar (Cedrus deodara), Chir Pine (Pinus roxburghii), Oak (Quercus leucotrichophora), and mixed broadleaf species. These forests differ considerably in litter quality, vegetation structure, microbial activity, and soil physicochemical properties, thereby influencing ecosystem functions. The present study evaluates soil health under major forest types of Shimla District using a review-based analytical approach based on published literature, Forest Survey of India reports, and recent ecological studies. Soil organic carbon, soil pH, available nitrogen, phosphorus, moisture content, microbial biomass, and carbon sequestration potential were considered as major indicators of soil quality. Evidence suggests that oak and mixed broadleaf forests possess higher soil organic carbon, improved nutrient availability, greater microbial activity, and better moisture retention than chir pine forests, whereas deodar forests exhibit intermediate soil characteristics. The findings highlight the ecological significance of conserving native broadleaf forests for maintaining soil fertility, biodiversity, and climate resilience in the north-western Himalaya. The study recommends sustainable forest management and continuous soil monitoring to preserve ecosystem functions under changing climatic conditions.***

**Keywords:** Soil health; Forest ecosystems; Ecosystem functions; Shimla District; Western Himalaya

## 1. Introduction

Forest ecosystems perform indispensable ecological functions by regulating hydrological cycles, conserving biodiversity, maintaining soil fertility, and mitigating climate change through carbon sequestration. Soil constitutes the fundamental component of these ecosystem services because it regulates nutrient availability, microbial diversity, vegetation productivity, and water retention. Healthy forest soils are therefore considered an essential indicator of ecosystem stability and resilience [1]. The Himalayan Mountain ecosystem is recognized as one of the world's most fragile ecological regions because of its steep terrain, heterogeneous climate, rich biodiversity, and increasing anthropogenic pressures. Rapid urbanization, changing land-use practices, tourism, forest fires, and climate change have accelerated soil degradation and altered ecosystem processes throughout the Indian Himalayan Region. Consequently, assessment of soil health has become an important component of sustainable forest management and environmental conservation [2,3]. Shimla District occupies a significant portion of the middle Himalayan zone of Himachal Pradesh and supports a wide range of forest types distributed along altitudinal gradients. Major forest communities include Deodar (*Cedrus deodara*), Chir Pine (*Pinus roxburghii*), Banj Oak (*Quercus leucotrichophora*), and mixed broadleaf forests. Differences in canopy structure, litter quality, decomposition rates, and microbial activity among these forest types directly influence soil organic carbon accumulation, nutrient cycling, moisture conservation, and biological productivity [4]. Among the various forest ecosystems, oak forests generally possess nutrient-rich litter that decomposes rapidly, enhancing microbial activity and improving soil fertility. In contrast, chir pine forests accumulate slowly decomposing needle litter that increases soil acidity and reduces nutrient turnover. Recent investigations in Himalayan forests have further demonstrated that soil microbial respiration, carbon dynamics, and moisture retention differ considerably between oak and chir pine ecosystems, influencing their resilience to climatic stress [5,6]. The India State of Forest Report 2023 indicates that Himachal Pradesh continues to possess substantial forest resources that contribute significantly to carbon storage, watershed protection, and biodiversity conservation. However, increasing climatic variability and anthropogenic disturbances necessitate continuous evaluation of soil quality under different forest ecosystems to ensure sustainable management of these valuable natural resources [4]. Assessment of soil health using indicators such as soil organic carbon, available nitrogen, phosphorus, soil pH, microbial biomass, and moisture content provides a reliable measure of ecosystem functioning. Comparative evaluation of these indicators across different forest types helps identify ecosystems with greater resilience and ecological stability while supporting evidence-based forest management strategies. Therefore, the present study aims to assess soil health and ecosystem functions under the major forest types of Shimla District by synthesizing available scientific literature and government reports. The study also highlights the ecological significance of conserving native broadleaf forests for enhancing ecosystem sustainability under changing environmental conditions.

## 2. Literature Review

Forest vegetation strongly influences soil properties through litter production, root activity, nutrient cycling, and microbial interactions. Several studies have demonstrated that

variations in forest composition produce significant differences in soil organic carbon, microbial biomass, moisture retention, and nutrient availability. Soil organic carbon is widely recognized as one of the most reliable indicators of soil quality because it influences physical, chemical, and biological properties simultaneously [1]. Broadleaf forests generally contribute larger quantities of nutrient-rich litter, which decomposes rapidly and improves nitrogen mineralization and phosphorus availability. In contrast, coniferous forests dominated by chir pine produce litter containing high lignin and resin concentrations that decompose slowly, resulting in lower nutrient turnover and comparatively acidic soils [5]. Recent studies conducted in the Central and Western Himalaya have reported significantly greater microbial respiration, soil moisture, and carbon sequestration in oak forests than in chir pine forests. These differences are primarily attributed to litter quality, canopy density, and favourable microclimatic conditions that promote microbial activity [5,6]. Forest disturbances such as fire, grazing, and land-use change also modify soil properties considerably. Research conducted in Himachal Pradesh has shown that recurrent forest fires in chir pine forests reduce soil organic matter, microbial biomass, and natural regeneration, thereby affecting long-term ecosystem functioning [7]. Similarly, studies on Himalayan montane forests indicate that disturbance gradients influence vegetation composition, soil characteristics, and total ecosystem carbon stocks [8]. The latest India State of Forest Report 2023 further emphasizes the importance of conserving native forest ecosystems for maintaining ecological stability, watershed protection, and carbon sequestration across Himalayan landscapes [4]. Collectively, these studies indicate that forest type is one of the principal determinants of soil health and ecosystem functioning in mountainous environments.

## 3. Materials and Methods

### Study Area

Shimla District is situated in the middle Himalayan region of Himachal Pradesh between approximately 30°45′–31°44′ N latitude and 76°59′–78°19′ E longitude, covering an area of about 5,131 km². Elevation ranges from nearly 300 m to over 6,000 m above mean sea level, creating remarkable variation in climate, vegetation, and soil characteristics. The district experiences temperate to alpine climatic conditions, with annual rainfall ranging between 1,000 and 1,500 mm, most of which is received during the southwest monsoon. Mean annual temperature varies from approximately 2°C during winter to 28°C during summer, depending upon altitude [9]. The forests of Shimla District are primarily represented by Deodar (*Cedrus deodara*), Chir Pine (*Pinus roxburghii*), Banj Oak (*Quercus leucotrichophora*), Kail (*Pinus wallichiana*), and mixed broadleaf species. These forests play an important role in watershed protection, biodiversity conservation, carbon sequestration, and livelihood support for local communities [4,9].

### Research Design

The present investigation employed a comparative descriptive research design based on secondary data collected from peer-reviewed scientific journals, reports published by the Forest Survey of India (FSI), Food and Agriculture Organization (FAO), Intergovernmental Panel on Climate Change (IPCC), Himachal Pradesh Forest Department, and published research conducted in the Indian Himalayan Region. The study compared soil health indicators under four dominant forest ecosystems: Deodar Forest, Chir Pine Forest, Oak Forest & Mixed Broadleaf Forest. Comparisons were made to evaluate differences in soil quality and ecosystem functioning under diverse vegetation types. Soil Health Indicators: The assessment was based upon widely accepted soil health indicators used in forest ecosystem studies [1,2,10]. These indicators included: Soil Organic Carbon (SOC), Soil pH, Available Nitrogen, Available Phosphorus, Available Potassium, Soil Moisture Content, Microbial Biomass Carbon, Carbon Sequestration Potential, Nutrient Cycling Efficiency. These variables collectively determine soil fertility, biological activity, productivity, and long-term ecosystem sustainability.

### Data Analysis

Published findings from previous studies were critically synthesized using comparative analysis. Forest types were compared with respect to nutrient dynamics, carbon accumulation, microbial activity, and ecosystem services. Similarities and differences among forest ecosystems were interpreted to evaluate their contribution toward ecosystem functioning in Shimla District.

## 4. Results and Discussion

The review indicates that soil health varies considerably among the dominant forest ecosystems of Shimla District because vegetation type directly influences litter quality, decomposition rate, nutrient cycling, and microbial activity [5,8]. Oak forests consistently demonstrated superior soil quality compared with other forest types. Higher concentrations of soil organic carbon, available nitrogen, and microbial biomass were observed because broadleaf litter decomposes rapidly, releasing nutrients into the soil. Dense canopy cover further enhances soil moisture retention while reducing erosion and evaporation losses [5,10]. Mixed broadleaf forests exhibited similar characteristics. Continuous addition of diverse leaf litter promoted microbial diversity and accelerated decomposition processes, thereby improving nutrient availability and increasing ecosystem productivity. These forests also showed higher carbon sequestration potential owing to greater biomass accumulation and improved soil carbon storage [8,11]. Deodar forests displayed intermediate soil characteristics. Although decomposition proceeds relatively slowly under coniferous litter, thick organic layers contribute to stable carbon accumulation and reduce soil erosion. Consequently, deodar forests continue to provide significant ecological services including watershed protection and slope stabilization [9,12]. Among all forest types, Chir Pine forests recorded comparatively lower soil fertility. Pine needles contain high lignin and resin content, which slows decomposition and limits nutrient release into the soil. Continuous accumulation of acidic litter reduces soil pH and microbial activity, thereby lowering nitrogen mineralization and nutrient cycling efficiency [5,7]. Human-induced disturbances such as forest fires, grazing, road construction, and urban expansion further accelerate soil degradation within chir pine forests. Studies from Himachal Pradesh have

demonstrated that repeated fires reduce soil organic carbon, microbial biomass, and natural regeneration, thereby weakening ecosystem resilience [7]. Climate change represents another major threat to Himalayan soil ecosystems. Increasing temperatures, irregular precipitation patterns, and prolonged droughts alter litter decomposition rates, microbial respiration, and soil moisture dynamics. Such changes are expected to influence long-term ecosystem productivity and carbon storage across temperate Himalayan forests [6,11]. Overall, the findings indicate that broadleaf forests maintain healthier soils than conifer-dominated ecosystems. Conservation of native oak forests therefore represents an important strategy for maintaining ecosystem services, biodiversity, and climate resilience within Shimla District.

**Table 1:** Comparative Soil Health under Different Forest Types

| Soil Health Parameter | Oak Forest | Mixed Broadleaf | Deodar Forest | Chir Pine Forest |
|---|---|---|---|---|
| Soil Organic Carbon | Very High | High | Moderate | Low |
| Soil Moisture | High | High | Moderate | Low |
| Soil pH | Nearly Neutral | Neutral | Slightly Acidic | Acidic |
| Available Nitrogen | High | High | Moderate | Low |
| Available Phosphorus | High | Moderate | Moderate | Low |
| Microbial Biomass | Very High | High | Moderate | Low |
| Nutrient Cycling | Excellent | Excellent | Good | Fair |
| Carbon Sequestration | Very High | High | Moderate | Moderate |
| Overall Soil Health | Excellent | Very Good | Good | Fair |

Source: Compiled from published studies [5,7,8,10–12].

## 5. Conclusion

The present study demonstrates that forest vegetation significantly influences soil health and ecosystem functioning in Shimla District of Himachal Pradesh. Comparative evaluation reveals that Oak and Mixed Broadleaf forests possess superior soil quality because of higher soil organic carbon, enhanced microbial activity, improved nutrient cycling, and greater moisture retention. In contrast, Chir Pine forests exhibit relatively poor soil fertility due to slower litter decomposition, acidic soil conditions, and reduced microbial biomass. Deodar forests occupy an intermediate position by maintaining stable carbon stocks and effective watershed protection. The study emphasizes that maintaining native broadleaf forests is essential for preserving ecosystem services, biodiversity, and long-term ecological stability in the Western Himalaya. Sustainable forest management, scientific monitoring of soil quality, and restoration of degraded forest ecosystems should therefore become important priorities for environmental policy and conservation planning.

## 6. Future Scope

Future investigations should incorporate extensive field-based sampling across different altitudinal gradients of Shimla District to validate the findings of the present review. Integration of Geographic Information Systems (GIS), Remote Sensing, soil microbial genomics, and machine learning-based ecological modelling can provide more accurate assessment of soil health under changing climatic conditions. Long-term monitoring programmes are also required to understand the cumulative impacts of climate change, forest fires, invasive species, and anthropogenic disturbances on Himalayan forest ecosystems.

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