Sustainable Forest Management and Its Role in Enhancing Soil Quality Across Different Forest Types in Shimla District, Himachal Pradesh: A Critical Review

Dr. Dhruv Sagar
Senior Project Associate at Forest Research Institute, Dehradun, Ph.D in Environmental Science, Dept. of Env Science, Dr. Y.S Parmar University of Horticulture and Forestry, Nauni Solan.

Abstract

Sustainable forest management (SFM) has become a cornerstone of global efforts to conserve biodiversity, maintain ecosystem services, and mitigate climate change. In the Himalayan region, where forests perform critical ecological functions under fragile environmental conditions, maintaining soil quality is fundamental to long-term ecosystem stability and productivity. Shimla District, Himachal Pradesh, comprises diverse forest ecosystems dominated by chir pine (*Pinus roxburghii*), deodar (*Cedrus deodara*), ban oak (*Quercus leucotrichophora*), kharsu oak (*Quercus semecarpifolia*), and mixed temperate forests. These forest types differ in litter quality, decomposition rates, nutrient cycling, and microbial activity, resulting in considerable variation in soil properties. This review critically examines how sustainable forest management influences soil quality across these forest ecosystems. Evidence from Himalayan studies indicates that broadleaved and mixed forests generally support higher soil organic carbon, nutrient availability, and microbial biomass than pure coniferous forests because of faster litter decomposition and more efficient nutrient recycling (Pal et al., 2013; Panwar et al., 2022; Sheikh et al., 2009). Sustainable management practices such as assisted natural regeneration, mixed-species forestry, litter conservation, and soil and water conservation further enhance soil fertility, carbon sequestration, and ecosystem resilience (Food and Agriculture Organization [FAO], 2022). The review highlights the importance of integrating ecological principles into forest management to maintain soil quality and identifies future research priorities for long-term monitoring and climate-resilient forest governance in Shimla District.

Keywords: Sustainable forest management; soil quality; Himalayan forests; Shimla District; soil organic carbon; nutrient cycling; ecosystem resilience

1. Introduction

Forest soils constitute the foundation of terrestrial ecosystems by regulating nutrient cycling, water availability, carbon sequestration, and vegetation productivity. Healthy soils sustain forest growth, support microbial diversity, and improve ecosystem resilience against climatic

*Corresponding Author Email: dsknauni1123@gmail.com
Published: 31 July 2026
DOI: https://doi.org/10.70558/IJMRS.2026.v2.i3.301138

and anthropogenic disturbances. Consequently, soil quality has emerged as one of the most important indicators of sustainable forest management (SFM), particularly in mountain ecosystems where steep slopes, fragile geology, and high rainfall increase susceptibility to erosion and nutrient depletion (Doran & Parkin, 1994; Karlen et al., 2003; Lehmann et al., 2020; Valani et al., 2021). The Indian Himalayan Region contains some of the country's most ecologically significant forests and stores substantial quantities of terrestrial soil organic carbon. Forest type, vegetation composition, altitude, and management practices strongly influence soil physical, chemical, and biological properties. Variations in litter production, decomposition rates, and root distribution determine the accumulation of soil organic matter and the availability of essential nutrients such as nitrogen, phosphorus, and potassium. Studies conducted across the north-western Himalaya consistently demonstrate that differences in forest composition lead to measurable variations in soil fertility, nutrient cycling, and ecosystem functioning (Pal et al., 2013; Panwar et al., 2022; Kumar et al., 2024). Shimla District occupies a unique ecological position within the Western Himalaya because it encompasses subtropical, temperate, and sub-alpine forest ecosystems dominated by chir pine (*Pinus roxburghii*), deodar (*Cedrus deodara*), ban oak (*Quercus leucotrichophora*), kharsu oak (*Quercus semecarpifolia*), and mixed broadleaved forests. These forests play a vital role in regulating watershed hydrology, conserving biodiversity, preventing soil erosion, and maintaining ecosystem services that support agriculture, tourism, and rural livelihoods. However, increasing urbanisation, infrastructure development, forest fires, and climate variability have intensified pressure on these ecosystems, highlighting the need for sustainable forest management strategies that simultaneously conserve forest productivity and soil quality (Kumar et al., 2025; Lal, 2021). Forest type exerts a significant influence on soil quality through its effects on litter characteristics, microbial activity, and nutrient cycling. Broadleaved forests generally produce litter with lower carbon-to-nitrogen ratios and higher nutrient concentrations, resulting in faster decomposition and greater nutrient release into the soil. Consequently, soils beneath broadleaved and mixed forests often exhibit higher soil organic carbon, microbial biomass, and available nitrogen than soils beneath pure coniferous stands (Pal et al., 2013; Panwar et al., 2022).

In contrast, coniferous forests typically accumulate thicker organic horizons because of slower decomposition of needle litter, enhancing carbon storage in the forest floor while reducing the rate of nutrient turnover (Prescott, 2010; Sheikh et al., 2009). Sustainable forest management seeks to maintain these ecological functions while ensuring that forests continue to provide environmental, economic, and social benefits for present and future generations. Contemporary forest management extends beyond timber production to include biodiversity conservation, carbon sequestration, watershed protection, ecological restoration, and climate-change mitigation. Practices such as mixed-species plantations, assisted natural regeneration, litter conservation, regulated grazing, and soil and water conservation have been shown to improve soil fertility, enhance microbial activity, increase carbon sequestration, and reduce soil degradation in Himalayan ecosystems (FAO, 2022; Karlen et al., 2003; Kumar et al., 2025; Panwar et al., 2022). Despite considerable research on Himalayan forest ecology, information integrating sustainable forest management with soil quality across the diverse forest types of Shimla District remains fragmented. Most available studies examine soil organic carbon, nutrient dynamics, vegetation composition, or biodiversity independently, with limited synthesis of their implications for sustainable forest management. Furthermore, relatively few studies have critically compared the influence of different forest types on soil quality within the ecological context of Shimla District. This review addresses that gap by critically evaluating current evidence on the role of sustainable forest management in enhancing soil quality across the principal forest ecosystems of Shimla District. It further discusses the implications of sustainable soil management for biodiversity conservation, watershed protection, climate resilience, and environmentally sustainable forest governance in the Western Himalaya.

2. Forest Ecosystems of Shimla District

Shimla District occupies a significant ecological position within the north-western Himalaya because of its remarkable altitudinal variation, ranging from approximately 300 m to over 4,500 m above sea level. This wide elevational gradient supports diverse climatic conditions and vegetation communities, making the district one of the richest forest landscapes in Himachal Pradesh (Forest Survey of India [FSI], 2023). The major forest types include subtropical chir pine (*Pinus roxburghii*) forests at lower elevations, temperate deodar (*Cedrus deodara*) forests, ban oak (*Quercus leucotrichophora*) forests, kharsu oak (*Quercus semecarpifolia*) forests, and mixed broadleaved forests containing species such as *Rhododendron arboreum*, *Acer* spp., *Aesculus indica*, and several understory shrubs and herbs (Champion & Seth, 1968; FSI, 2023).

These forest ecosystems provide numerous ecological services including carbon sequestration, regulation of hydrological processes, biodiversity conservation, prevention of soil erosion, slope stabilization, and maintenance of nutrient cycles. They also support local livelihoods through non-timber forest products, grazing resources, ecotourism, and watershed protection. Consequently, the ecological integrity of these forests is closely linked with the environmental and socio-economic sustainability of Shimla District (FAO, 2022; IPCC, 2022).

Forest composition exerts a profound influence on soil formation because vegetation determines both the quantity and quality of organic matter entering the soil. Variations in litter chemistry, root biomass, canopy density, and nutrient uptake among tree species regulate decomposition rates, microbial activity, soil acidity, and nutrient availability (Prescott, 2010). Consequently, forest soils developing under different vegetation types often exhibit substantial differences in their physical, chemical, and biological characteristics despite experiencing similar climatic conditions (Pal et al., 2013).

Studies conducted across the north-western Himalaya consistently indicate that broadleaved forests possess comparatively higher soil fertility than coniferous forests. Oak forests generally accumulate greater quantities of soil organic carbon owing to the rapid decomposition of nutrient-rich litter with relatively low carbon-to-nitrogen ratios. The faster decomposition process enhances microbial activity, accelerates nutrient mineralisation, and improves aggregate stability, thereby increasing soil moisture retention and nutrient availability (Panwar et al., 2022; Sheikh et al., 2009). Similar observations have been reported from temperate Himalayan forests where broadleaved stands maintain significantly higher concentrations of available nitrogen, phosphorus, potassium, and microbial biomass than adjacent coniferous forests (Pal et al., 2013).

Conversely, chir pine forests are characterised by slowly decomposing needle litter containing relatively high lignin and resin content. The slower decomposition process results in the accumulation of thick organic layers on the forest floor, enhancing long-term carbon storage but reducing the rate of nutrient recycling. Although pine forests generally exhibit comparatively lower nutrient availability than broadleaved forests, they play an indispensable ecological role in stabilising fragile mountain slopes, protecting watersheds, and conserving soil under drought-prone conditions (Prescott, 2010; Singh et al., 1997).

Deodar forests occupy an intermediate ecological position between pine and broadleaved ecosystems. Mature deodar stands produce substantial quantities of litter and possess extensive root systems that improve soil structure and reduce erosion. Under undisturbed conditions, these forests maintain moderate to high soil organic carbon stocks while supporting diverse microbial communities and efficient nutrient cycling. Their ecological significance extends beyond timber production to include watershed protection and biodiversity conservation throughout the middle Himalayan region (FSI, 2023; Singh et al., 1997).

Altitude further modifies soil quality by influencing temperature, precipitation, vegetation composition, and decomposition rates. Lower temperatures at higher elevations generally slow microbial decomposition, allowing greater accumulation of soil organic matter and carbon. Conversely, warmer lower elevations favour rapid nutrient cycling but often experience greater nutrient losses through accelerated decomposition and erosion. Soil quality therefore represents the combined influence of altitude, slope, aspect, parent material, vegetation type, and forest management rather than any single ecological factor (Kumar et al., 2024; Sheikh et al., 2009).

The ecological diversity of Shimla District highlights the importance of conserving heterogeneous forest landscapes rather than promoting extensive monoculture plantations. Maintaining a mosaic of coniferous and broadleaved forests enhances ecosystem resilience by ensuring complementary ecological functions such as carbon sequestration, biodiversity conservation, nutrient cycling, and watershed protection. Sustainable forest management should therefore prioritise landscape-level ecological integrity alongside timber production.

3. Influence of Sustainable Forest Management on Soil Quality

Sustainable forest management is founded on the principle of maintaining forest productivity while conserving biodiversity, ecological processes, and ecosystem services for future generations (FAO, 2022). Unlike conventional forestry, which primarily emphasises timber extraction, sustainable forest management integrates environmental conservation, climate-change mitigation, watershed protection, and soil restoration into forest planning and management. Since soil serves as the foundation of all forest ecosystem processes, maintaining soil quality has become a central objective of sustainable forestry worldwide (Karlen et al., 2003; Lehmann et al., 2020).

One of the most significant contributions of sustainable forest management is the conservation of soil organic carbon (SOC). Soil organic carbon improves soil structure, enhances aggregate stability, increases water-holding capacity, and serves as the principal source of energy for soil microorganisms. Forest management practices that minimise soil disturbance, conserve litter, encourage natural regeneration, and reduce excessive harvesting significantly increase carbon inputs while limiting carbon losses caused by erosion and oxidation (FAO, 2022). Long-term studies conducted in Himalayan forests demonstrate substantially greater SOC accumulation under sustainably managed forests than under degraded or disturbed forest ecosystems (Kumar et al., 2024; Panwar et al., 2022).

Nutrient cycling constitutes another fundamental mechanism through which sustainable forest management improves soil quality. Continuous removal of forest litter, uncontrolled grazing, repeated forest fires, and excessive harvesting reduce organic matter inputs, thereby interrupting nutrient cycling and accelerating nutrient depletion. Conversely, retaining litter on the forest floor enhances microbial decomposition, increases humus formation, and gradually releases essential nutrients such as nitrogen, phosphorus, and potassium into the soil. Mixed-species forests further improve nutrient cycling because different tree species contribute litter of varying chemical composition, thereby promoting continuous nutrient availability throughout the year (Pal et al., 2013; Panwar et al., 2022; Prescott, 2010).

The biological properties of forest soils are equally important indicators of soil quality. Soil microorganisms regulate decomposition, nutrient mineralisation, nitrogen fixation, and humus formation, making microbial biomass a sensitive indicator of ecosystem health (Lehmann et al., 2020). Sustainable forest management practices that preserve canopy cover, minimise soil compaction, and maintain organic matter create favourable habitats for diverse microbial communities. Enhanced microbial diversity subsequently accelerates nutrient transformation and contributes to greater forest productivity and ecological resilience (FAO, 2022).

Forest management also significantly influences the physical properties of soil. Dense vegetation cover protects the soil surface from raindrop impact, reduces surface runoff, increases water infiltration, and limits soil erosion on steep Himalayan slopes. Improved soil aggregation decreases bulk density while increasing porosity and moisture retention. These improvements are particularly important in Shimla District, where intense monsoon rainfall frequently triggers landslides and sediment transport. By reducing erosion and improving infiltration, sustainable forest management protects downstream river systems, reservoirs, and agricultural lands (IPCC, 2022; Lal, 2021).

An additional benefit of sustainable forest management lies in its contribution to climate-change adaptation. Healthy forest soils store large quantities of carbon while simultaneously improving ecosystem resistance to droughts, floods, and extreme weather events. Forest restoration, assisted natural regeneration, enrichment planting with native species, and conservation of degraded landscapes increase ecosystem resilience and strengthen long-term carbon sequestration capacity. Consequently, sustainable forest management contributes not only to local soil conservation but also to national and global climate-change mitigation strategies (FAO, 2022; IPCC, 2022).

Collectively, current scientific evidence demonstrates that sustainable forest management enhances soil quality through interconnected physical, chemical, and biological processes. Rather than viewing soil merely as a medium for tree growth, contemporary forest management recognises soil as the foundation of ecosystem functioning. Consequently, conserving soil quality should remain a central objective of sustainable forest management policies in Shimla

District to ensure long-term ecological stability, biodiversity conservation, watershed protection, and climate resilience.

4. Policy Implications and Future Research

The findings of this review clearly indicate that sustainable forest management should be viewed as an integrated strategy for maintaining forest productivity, conserving biodiversity, and enhancing soil quality rather than merely regulating timber extraction. Soil quality constitutes the ecological foundation upon which nutrient cycling, carbon sequestration, vegetation productivity, and hydrological stability depend. Consequently, forest management policies in Shimla District should incorporate soil quality indicators such as soil organic carbon, nutrient availability, microbial biomass, bulk density, infiltration capacity, and erosion susceptibility into routine forest monitoring programmes (Doran & Parkin, 1994; FAO, 2022; Forest Survey of India [FSI], 2024).

One of the foremost policy priorities should be the promotion of mixed-species forestry instead of extensive monoculture plantations. Native broadleaved species, particularly oaks (*Quercus leucotrichophora* and *Quercus semecarpifolia*), produce nutrient-rich litter that decomposes rapidly, thereby improving nutrient availability and enhancing microbial activity. Integrating these species with coniferous forests can strengthen ecosystem resilience while simultaneously maintaining carbon storage and improving soil fertility (Pal et al., 2013; Panwar et al., 2022; Prescott, 2010).

Conservation of the forest floor should receive equal attention within sustainable forest management programmes. Excessive litter removal, uncontrolled grazing, and repeated forest fires significantly reduce soil organic matter and interrupt nutrient cycling. Policies encouraging litter retention, regulated grazing, community-based forest protection, and effective fire management can substantially improve long-term soil health and reduce erosion risks in the fragile Himalayan landscape (FAO, 2022; Lal, 2021).

Climate change further reinforces the importance of sustainable forest management in Shimla District. Rising temperatures, changing precipitation patterns, and increasing frequency of extreme rainfall events are expected to accelerate soil erosion, alter nutrient dynamics, and affect forest regeneration. Climate-resilient forestry should therefore prioritise restoration of degraded forests, assisted natural regeneration, enrichment planting with indigenous species, and conservation of ecologically sensitive watersheds. Such interventions simultaneously improve soil quality, enhance biodiversity, and strengthen ecosystem resilience against future climatic disturbances (IPCC, 2022).

Future scientific research should move beyond isolated assessments of soil chemistry and adopt multidisciplinary approaches integrating soil science, forestry, hydrology, ecology, remote sensing, and climate science. Long-term ecological monitoring plots established across different altitudinal zones of Shimla District would provide valuable information on temporal changes in soil organic carbon, microbial diversity, nutrient cycling, and vegetation dynamics. Such monitoring would also facilitate evaluation of the effectiveness of sustainable forest management practices under changing climatic conditions (Minasny et al., 2017).

Recent advances in Geographic Information Systems (GIS), remote sensing, LiDAR, hyperspectral imaging, and machine learning provide powerful tools for spatial assessment of forest health and soil quality. Integrating these technologies into forest management can improve identification of erosion-prone areas, monitor changes in vegetation cover, estimate soil carbon stocks, and support evidence-based decision-making. Combining field observations with geospatial modelling would enable more efficient planning of restoration programmes and sustainable land-use management throughout the Western Himalaya (FSI, 2024; Minasny et al., 2017).

Future research should also investigate the influence of invasive plant species, forest fragmentation, tourism, and expanding infrastructure on soil biological properties. Although several studies have examined soil organic carbon and nutrient dynamics in Himalayan forests, comparatively little attention has been paid to soil microbial diversity, enzyme activity, fungal communities, and belowground ecological interactions. Addressing these research gaps would significantly improve understanding of ecosystem functioning and contribute to more effective sustainable forest management strategies.

5. Conclusion

Healthy forest soils are indispensable for maintaining the ecological integrity, productivity, and resilience of Himalayan Forest ecosystems. This review demonstrates that sustainable forest management significantly enhances soil quality by improving nutrient cycling, increasing soil organic carbon accumulation, supporting microbial diversity, and strengthening soil physical properties. These improvements collectively enhance forest productivity while simultaneously contributing to biodiversity conservation, watershed protection, and climate-change mitigation. Forest type plays a decisive role in determining soil characteristics across Shimla District. Broadleaved and mixed forests generally exhibit higher nutrient availability, greater microbial biomass, and faster nutrient cycling because of the rapid decomposition of nutrient-rich litter. Conversely, coniferous forests, particularly chir pine and deodar, contribute substantially to long-term carbon storage, slope stabilisation, and watershed conservation despite comparatively slower nutrient turnover. These findings suggest that both broadleaved and coniferous forests perform complementary ecological functions that are essential for sustaining healthy mountain ecosystems.The evidence reviewed indicates that sustainable forest management practices—including mixed-species forestry, assisted natural regeneration, litter conservation, regulated grazing, soil and water conservation, and ecological restoration—substantially improve soil quality while increasing ecosystem resilience. These practices should therefore form the foundation of future forest policies in Shimla District. Given the increasing pressures of climate change, infrastructure expansion, tourism, and anthropogenic disturbances, conservation of forest soils must become a central component of regional environmental planning. Protecting soil quality not only enhances forest productivity but also strengthens watershed stability, reduces erosion, improves carbon sequestration, and safeguards biodiversity throughout the Western Himalaya. Finally, continued investment in long-term ecological monitoring, advanced geospatial technologies, interdisciplinary research, and evidence-based policymaking will be essential for ensuring the sustainable management of Shimla District's forest ecosystems. Sustainable forest management should therefore be recognised not merely as a forestry practice but as a comprehensive ecological strategy for conserving natural resources and promoting environmental sustainability in the Himalayan region.

References:

Andrews, S. S., Karlen, D. L., & Mitchell, J. P. (2002). A comparison of soil quality indexing methods for vegetable production systems. *Soil Science Society of America Journal, 66*(6), 1882–1890.

Champion, H. G., & Seth, S. K. (1968). *A revised survey of the forest types of India*. Government of India Press.

Doran, J. W., & Parkin, T. B. (1994). Defining and assessing soil quality. In J. W. Doran, D. C. Coleman, D. F. Bezdicek, & B. A. Stewart (Eds.), *Defining soil quality for a sustainable environment* (SSSA Special Publication No. 35, pp. 3–21). Soil Science Society of America.

Food and Agriculture Organization. (2022). *Sustainable forest management toolbox*. FAO.

Forest Survey of India. (2023). *India state of forest report 2023*. Ministry of Environment, Forest and Climate Change, Government of India.

Forest Survey of India. (2024). *National forest inventory report*. Ministry of Environment, Forest and Climate Change, Government of India.

Intergovernmental Panel on Climate Change. (2022). *Climate change 2022: Impacts, adaptation and vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press.

Karlen, D. L., Ditzler, C. A., & Andrews, S. S. (2003). Soil quality: Why and how? *Geoderma, 114*(3–4), 145–156.

Kumar, J., Kalita, H., Alone, R. A., Sinha, N. K., Rani, A., Kumar, D., et al. (2025). Multivariate assessment of soil quality across different land-use types in the hilly terrain of subtropical India. *Soil and Water Research, 20*(3), 178–194.

Kumar, S., Prabhakar, M., Bhardwaj, D. R., Thakur, C. L., Kumar, J., & Sharma, P. (2024). Altitudinal and aspect-driven variations in soil carbon storage potential in subtropical Himalayan forest ecosystems. *Environmental Monitoring and Assessment, 196*, 126.

Lal, R. (2021). Sustainable soil management for food security in South Asia. *Journal of Soil Science and Plant Nutrition, 21*, 258–275.

Lehmann, J., Bossio, D. A., Kögel-Knabner, I., & Rillig, M. C. (2020). The concept and future prospects of soil health. *Nature Reviews Earth & Environment, 1*(10), 544–553.

Minasny, B., Malone, B. P., McBratney, A. B., Angers, D. A., Arrouays, D., Chambers, A., et al. (2017). Soil carbon 4 per mille. *Geoderma, 292*, 59–86.

Pal, S., Panwar, P., & Bhardwaj, D. R. (2013). Soil quality under forest compared to other land uses in acid soils of north-western Himalaya, India. *Annals of Forest Research, 56*(1), 187–198.

Panwar, P., Pal, S., Verma, S., Loria, N., Verma, M. R., Bhatt, V. K., et al. (2022). Long-term impact of forest-based land uses on soil quality indicators in the Himalayan region. *Agricultural Research, 11*(2), 204–214.

Prescott, C. E. (2010). Litter decomposition: What controls it and how can we alter it to sequester more carbon in forest soils? *Biogeochemistry, 101*(1–3), 133–149.

Sheikh, M. A., Kumar, M., & Bussmann, R. W. (2009). Altitudinal variation in soil organic carbon stock in coniferous subtropical and broadleaf temperate forests in Garhwal Himalaya. *Carbon Balance and Management, 4*, Article 6.

Singh, S. P., Rawat, Y. S., & Garkoti, S. C. (1997). Himalayan forest ecosystems: Structure, functioning and management. *Ambio, 26*(5), 344–349.

Valani, G. P., Martíni, A. F., da Silva, L. F. S., Bovi, R. C., & Cooper, M. (2021). Soil quality assessments in integrated crop–livestock–forest systems: A review. *Soil Use and Management, 37*(1), 22–36.