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Carbon Sequestration Potential of Temperate Forests for Climate Change Mitigation in the Kashmir Himalayas

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The global carbon cycle relies greatly on biomass stored in forest ecosystems. More than 50% of the global gross primary output is accounted by forests which alone represent nearly 48% of the planet's total terrestrial carbon. Temperate forests of the Kashmir Himalayas represent one of the most ecologically significant and carbon-rich ecosystems of the Indian subcontinent (Dar and Parthasarathy, 2022). Stretching across altitudes ranging from 1,500 to 3,500 meters above sea level, these forests are dominated by conifers such as *Cedrus deodara* (Deodar), *Abies pindrow* (Himalayan fir), *Picea smithiana* (Spruce) and broadleaved species such as *Quercus leucotrichophora* and *Aesculus indica* (Shaheen *et al*., 2012). These forests act as vital carbon sinks, playing a pivotal role in regulating regional and global climate through the process of carbon sequestration.

Carbon sequestration refers to the long-term removal and storage of atmospheric carbon dioxide (CO_2) in forests, soils and other biological systems. The amount of total biomass stored in a forest indicates the quantity of carbon (C) that can be sequestered to meet the emission targets. With rising global temperatures and increasing greenhouse gas (GHG) emissions, forests have emerged as one of the most cost-effective and natural tools for climate change mitigation. The temperate forests of Jammu & Kashmir (Figure 1), covering approximately 25,013.36 sq. km which accounts for approximately 39.07% of its digitized boundary (FSI, 2023), hold immense potential for carbon storage in their biomass, deadwood, litter and soil organic matter. Despite their ecological significance, quantitative assessments of carbon stocks in J&K's temperate forests remain limited, and there is an urgent need for scientific estimation to support policy planning and REDD+ initiatives. Currently, climate change is a global concern, and forests plays vital role in climate change regulation and mitigation through reducing CO_2 concentrations in the atmosphere (Rawat and Rawat, 2025).

a) Shankaracharya Forest Division | b) Special Forest Division Kulgam

Figure 1. Temperate forests of Kashmir

Carbon Pools in Temperate Forests

Carbon is stored in five major pools in forest ecosystems: (i) above-ground biomass (AGB), which includes the stems, branches and foliage of living trees (ii) below-ground biomass (BGB), primarily the root systems (iii) deadwood, comprising standing dead trees and fallen logs (iv) litter, including leaf fall and fine debris on the forest floor; and (v) soil organic carbon (SOC), the largest and most stable pool (Joshi *et al*., 2021). In temperate Himalayan forests, the above-ground biomass constitutes the dominant carbon pool. The Deodar-dominated forests of Kashmir are known to be among the highest biomass-accumulating forest types in the Indian Himalayan Region (IHR).

Carbon Stock Estimation Methods

Carbon stocks in temperate forests are estimated using various methods including allometric equations, forest inventory data and remote sensing techniques. The IPCC (2006) guidelines recommend a tiered approach where Tier 1 uses default emission factors, Tier 2 applies country-specific data and Tier 3 employs detailed ground-level measurements (IPCC, 2006). In J&K, the Forest Survey of India (FSI) conducts growing stock assessments through State of Forest Reports (SFR), which can be converted to biomass and carbon stock using biomass expansion factors (BEFs) and wood density values (FSI, 2023). Species-specific allometric equations developed for Himalayan conifers by researchers at Forest Research Institute (FRI), Dehradun and SKUAST-Kashmir are widely used for ground-based estimation.

Role of Temperate Forests in Climate Regulation

The temperate forests of Kashmir play a significant role in climate regulation beyond carbon sequestration. They influence local precipitation patterns, moderate temperature extremes and maintain soil moisture through evapotranspiration. The forests also protect watersheds feeding major rivers like the Jhelum, Chenab and their tributaries, which are critical for agriculture and drinking water in both J&K and downstream regions. According to FSI State of Forest Report 2023, Jammu & Kashmir has recorded a net increase in forest cover, particularly in open and moderately dense forests, indicating active biomass accumulation and potential for enhanced carbon sequestration.

REDD+ and Carbon Trading

Reducing Emissions from Deforestation and Forest Degradation (REDD+) is a global framework under the UNFCCC that motivates developing countries to conserve and sustainably manage their forests in exchange for carbon credits. The temperate forests of J&K, if brought under a robust REDD+ monitoring framework, can generate significant carbon credits that could be channelled back to local forest-dependent communities for livelihood improvement. The Government of India's Green Credit Programme (GCP) and National Action Plan on Climate Change (NAPCC) further support the recognition of forest carbon stocks as national assets.

Threats and Challenges

Despite their immense potential, the carbon sequestration capacity of J&K's temperate forests is threatened by several factors. Unregulated grazing, illegal felling, forest fires, encroachment and climate-induced shifts in species composition are major concerns. Rising temperatures have accelerated tree mortality, particularly among subalpine species near the treeline ecotone. Insect pest outbreaks such as those caused by bark beetles have also been reported in stressed conifer stands. Furthermore, land use changes due to horticulture expansion, infrastructure development and tourism pressures have resulted in fragmentation of contiguous forest patches, reducing their effectiveness as carbon sinks.

Conclusion

The temperate forests of the Kashmir Himalayas are among the most important carbon reservoirs in South Asia. The forest carbon assessment would boost the efficiency of incentive-based conservation schemes for combating climate, particularly the REDD+

initiative. Both the positive and negative aspects of REDD+ have promising importance in Kashmir Himalaya. The area is intended to gain most from negative REDD+ choices since it has primarily experienced forest loss in the past. Knowledge of tree species with regard to carbon stores and degrees of vulnerability in forest stands helps develop successful REDD+ measures to protect tree biodiversity and linked socioeconomic implications for the local population. The rigorous quantification of carbon would stimulate more robust community engagement in forest-based mitigation efforts. Understanding forest types and the factors that contribute to high carbon accumulation can help identify key conservation priorities. Conserving carbon-rich forests from human-induced disturbances can significantly reduce CO_2 emissions, while also enhancing carbon sequestration to offset existing losses. A deeper understanding of the relationship between forest carbon stocks, environmental conditions and forest structure is essential for predicting the impacts of climate change and improving the role of forests in carbon mitigation. This can be achieved by increasing carbon uptake, maintaining carbon reserves within forest stands and minimizing carbon loss through improved forest resilience. With appropriate policy support, scientific investment and international cooperation, J&K's temperate forests can serve as a model for forest-based climate solutions in the Himalayan region.

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