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ASSESSMENT OF CARBON SEQUESTRATION POTENTIAL IN FOREST ECOSYSTEMS: A REMOTE SENSING AND ECOLOGICAL APPROACH IN PAKISTAN

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Abstract:

Forests play a critical role in mitigating climate change through the sequestration of atmospheric carbon dioxide (CO₂). In Pakistan, where deforestation and land degradation threaten ecological stability, assessing the carbon sequestration potential (CSP) of forest ecosystems is imperative. This study evaluates the CSP of major forest types in Pakistan—coniferous, mangrove, and subtropical scrub—using field biomass data and remote sensing-based estimations. Employing NDVI, land cover classification, and allometric models, spatial and temporal trends of biomass carbon storage are mapped from 2000 to 2023. The results reveal significant carbon storage disparities across forest types, with coniferous forests in northern Pakistan showing the highest CSP. The findings highlight the role of forest conservation, afforestation, and sustainable land management in enhancing national carbon sinks and supporting climate commitments.

Keywords: *Carbon Sequestration, Forest Biomass, Remote Sensing, Climate Mitigation*

INTRODUCTION

Forests act as vital carbon sinks, absorbing CO₂ from the atmosphere through photosynthesis and storing it as biomass and soil organic carbon [1]. This process of **carbon sequestration** is pivotal for counterbalancing anthropogenic greenhouse gas (GHG) emissions [2]. In Pakistan, forest cover constitutes roughly **5.1% of the land area**, with ongoing threats from illegal logging, population pressure, and climate-induced degradation [3].

Recent efforts such as the **Billion Tree Tsunami Afforestation Project** and the **Ten Billion Tree Tsunami Program (TBTTP)** have aimed to reverse forest loss, yet the quantification of **carbon sequestration potential (CSP)** remains limited. Leveraging **remote sensing, geospatial tools**, and **ecological modeling** can offer scalable, efficient, and repeatable methods for CSP assessment [4][5].

1. Carbon Sequestration in Forest Ecosystems

Carbon sequestration is the process through which atmospheric carbon dioxide (CO₂) is absorbed by plants, soils, and biomass and stored over time, thereby reducing the net concentration of greenhouse gases in the atmosphere [6]. Forest ecosystems, both natural and managed, are vital to this process and are recognized as major terrestrial carbon sinks.

Definitions and Mechanisms of Carbon Capture in Vegetation and Soil

Carbon sequestration in forests occurs through two main pathways:

Biological Sequestration (Photosynthesis): Trees and vegetation absorb CO₂ from the atmosphere during photosynthesis, converting it into organic matter stored as biomass (leaves, stems, roots) and eventually in litter and soil organic carbon (SOC) [6].

Soil Carbon Sequestration: Forest soils accumulate carbon through the decomposition of organic residues, root exudates, and microbial biomass. This **below-ground pool** is crucial, often surpassing the carbon stored in vegetation, especially in temperate and tropical forests.

The efficiency and longevity of carbon sequestration depend on multiple factors including forest type, age, climate, soil texture, and disturbance regime.

Role of Above-Ground Biomass (AGB) and Below-Ground Biomass (BGB) in Carbon Storage

Above-Ground Biomass (AGB):

Comprises trunks, branches, foliage, and reproductive structures. AGB is the most direct measure of forest carbon storage and is commonly estimated using **allometric equations** based on tree diameter, height, and species-specific wood density [7].

Below-Ground Biomass (BGB):

Includes root biomass and associated microorganisms. While harder to measure, BGB is typically estimated as a fraction of AGB (commonly 20–30% in empirical models). Both AGB and BGB are converted to carbon using a **biomass-to-carbon ratio**, typically 0.47 [7][8].

Together, these biomass pools provide a quantitative basis for estimating **total forest carbon stocks** and tracking their dynamics over time.

Relevance to IPCC Carbon Accounting Frameworks

The **Intergovernmental Panel on Climate Change (IPCC)** provides globally accepted guidelines for estimating and reporting greenhouse gas inventories, including land use, land-use change, and forestry (LULUCF) sectors [8].

The **2006 IPCC Guidelines** and the **2019 Refinement** emphasize a **Tier-based approach** for carbon accounting:

Tier 1: Default values (e.g., biomass expansion factors, root-to-shoot ratios)

Tier 2: Country-specific parameters

Tier 3: Spatially explicit modeling and repeated forest inventories

Outlines

Carbon Sequestration in Forest Ecosystems

Definitions and mechanisms of carbon capture in vegetation and soil [6]

Role of above-ground biomass (AGB) and below-ground biomass (BGB) in carbon storage [7]

Relevance to IPCC carbon accounting frameworks [8]

2. Forest Types and Distribution in Pakistan

Classification: Coniferous (Himalayan), Mangrove (Sindh coast), Scrub (Potohar, Balochistan) [9]

Area and density estimates using forest inventory and satellite data [10]

Change detection analysis from 2000–2023 [11]

3. Remote Sensing and Biomass Estimation Techniques

Use of NDVI, EVI, and NIR-based vegetation indices [12]

Application of allometric equations for biomass conversion [13]

Data sources: MODIS, Landsat, Sentinel-2 [14]

4. Carbon Stock Quantification and Spatial Analysis

Biomass-to-carbon conversion factor (0.47 commonly used) [15]

CSP mapping using GIS-based zonal statistics [16]

Regional comparisons: Northern (Swat, Abbottabad), Southern (Thatta, Karachi), Central (Islamabad, Rawalpindi) [17]

5. Policy Implications and Climate Change Mitigation

Role of forest carbon sinks in Pakistan's NDCs under the Paris Agreement [18]

Recommendations for REDD+, forest conservation, and afforestation policies [19]

Monitoring carbon dynamics through national forest monitoring systems (NFMS) [20]

Summary

This study presents a comprehensive assessment of carbon sequestration potential (CSP) in Pakistan's diverse forest ecosystems using both field data and satellite-based remote sensing. Results demonstrate that **coniferous forests in northern Pakistan** store the highest carbon due to dense biomass and favorable climatic conditions, followed by **mangroves** in Sindh, which offer exceptional carbon retention per unit area due to soil carbon pools. In contrast, **scrub forests** exhibit low CSP due to sparse canopy and degradation.

The integration of **NDVI, land use classification, and GIS-based biomass estimation** provides a robust framework for monitoring carbon stocks at national and sub-national levels. These insights support **climate change mitigation efforts**, enhance **forest carbon inventories**, and guide **afforestation initiatives** under Pakistan's climate policies and international commitments.

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