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Re-evaluating the Role of Wetland Restoration in Enhancing Carbon Sequestration and Biodiversity Conservation

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ABSTRACT

Wetlands are among the most productive ecosystems on Earth, providing critical ecological services such as water purification, flood regulation, carbon sequestration, and biodiversity conservation. In India, these ecosystems have immense ecological and socio-economic significance, yet they face severe degradation due to anthropogenic pressures, urban expansion, and agricultural encroachment. This review examines the current understanding of wetland restoration in India and its dual role in enhancing carbon sequestration and biodiversity conservation. Drawing upon recent research and case studies from different regions of India, the paper highlights the potential of both freshwater and coastal wetlands to serve as natural climate solutions. It also identifies the challenges, gaps, and opportunities in restoration practices and policy implementation. The review concludes that comprehensive restoration programs, backed by scientific monitoring, policy coherence, and community participation, are essential for maximizing the ecological and climate benefits of wetlands in India.

Keywords: *Wetland restoration, Carbon sequestration, Biodiversity conservation, India, Ramsar sites, Mangroves, Freshwater wetlands*

1. Introduction

Wetlands are recognized globally as one of the most vital ecosystems due to their ability to provide multiple ecological services simultaneously. They act as carbon sinks, biodiversity reservoirs, and natural buffers against floods and droughts. India, with its diverse topography and climate, supports a vast array of wetland types, including inland freshwater wetlands, floodplain lakes, mangroves, marshes, and artificial reservoirs [1]. Despite their importance, Indian wetlands have been rapidly declining in extent and quality due to urbanization, industrial discharge, agricultural runoff, and poor management practices. The loss of wetlands not only diminishes biodiversity but also reduces their carbon storage capacity, thereby exacerbating the effects of climate change.

Wetland restoration has emerged as a critical strategy for achieving multiple environmental goals simultaneously—climate change mitigation through carbon sequestration, enhancement of biodiversity, and improvement of local livelihoods [2]. The objective of this review is to reassess the role of wetland restoration in India in enhancing carbon sequestration and biodiversity conservation. It synthesizes findings from recent Indian and international studies, evaluates policy frameworks, and identifies research gaps and management priorities.

2. Wetland Carbon Sequestration Potential in India

Wetlands have exceptional carbon sequestration potential because of their high primary productivity and low decomposition rates under anaerobic conditions. In India, both inland and coastal wetlands contribute significantly to carbon storage.

Freshwater wetlands such as floodplains, oxbow lakes, and marshes store considerable amounts of soil organic carbon (SOC) [2]. For instance, in the Lower Gangetic Basin of West Bengal, carbon stocks in various wetland types—sewage-fed, floodplain, and oxbow—were found to range between 48.53 and 143.17 Mg C per hectare in the top 30 cm of soil, far exceeding those in adjacent uplands [2]. Similarly, in Assam's wetlands, total soil carbon stock varied from 12,650 to 76,950 kg C per hectare depending on vegetation density and macrophyte cover [1]. These figures underscore the critical role of wetland vegetation and hydrology in carbon sequestration [4]. Coastal wetlands, particularly mangrove forests, are globally recognized for their enormous carbon storage capacity. Indian mangroves, spread across about 4,900 km^2, store significant amounts of both biomass and sediment carbon. Studies have shown that mangroves along the eastern coast of India can sequester up to 1.5 metric tonnes of carbon per hectare per year [4]. The Sundarbans, India's largest mangrove ecosystem, serves as a global carbon sink and supports high faunal diversity. However, salinity intrusion, aquaculture expansion, and land-use change continue to threaten their integrity.A recent line of research emphasizes “teal carbon,” a term describing carbon stored in non-tidal freshwater wetlands. India's first study on teal carbon conducted in Keoladeo National Park, Rajasthan, demonstrated that freshwater wetlands could make substantial contributions to national carbon budgets when vegetation biomass, microbial activity, and sediment carbon are included [7]. Despite this potential, freshwater wetlands remain underrepresented in India's carbon accounting and policy frameworks.

Table 1: Carbon Stocks in Selected Indian Wetlands

Wetland	Location	Type	Soil Depth (cm)	Carbon Stock (Mg C/ha)	Reference
East Kolkata Wetlands	West Bengal	Freshwater sewage-fed	0–30	48.53–143.17	[2]
Rudrasagar Lake	Tripura	Freshwater lake	0–30	12.65–76.95	[6]
Timbi Reservoir	Gujarat	Suburban reservoir	0–15	76.2	[4]
Keoladeo National Park	Rajasthan	Freshwater wetland (teal carbon)	0–20	55–92	[7]
Sundarbans Mangroves	West Bengal	Coastal mangrove	0–50	150–180	[4]

Table 2: Biodiversity Outcomes of Wetland Restoration in India

Wetland	Restoration Approach	Key Flora & Fauna Recovery	Notable Outcomes	Reference
East Kolkata Wetlands	Replanting macrophytes, hydrological restoration	Increased macrophyte diversity, fish population recovery	Improved habitat quality and carbon input	[5]
Rudrasagar Lake	Hydrological reconnection	Native aquatic plants, migratory birds	Recovery of species richness	[6]
Keoladeo National Park	Water regime management, invasive species removal	Wetland birds, amphibians, macrophytes	Increased functional diversity	[7]
Sundarbans Mangroves	Afforestation, tidal restoration	Mangrove species, crustaceans, fish	Enhanced carbon storage, biodiversity conservation	[4]

Table 3: Wetland Restoration Techniques and Effectiveness

Technique	Description	Wetland Type	Primary Benefit	Limitations	Reference
Hydrological restoration	Reconnecting channels, restoring natural inflows	Freshwater, coastal	Improves water availability, carbon storage	Requires continuous monitoring	[2],[6]
Vegetative restoration	Planting native macrophytes or mangroves	Freshwater, mangrove	Enhances carbon sequestration, provides habitat	Time-intensive, requires maintenance	[4],[5]
Pollution control	Sewage treatment, nutrient management	Urban wetlands	Improves water quality, supports biodiversity	Infrastructure costs	[5]
Community engagement	Co-management with local users	All wetland types	Ensures sustainability, improves compliance	Needs training and incentives	[3]

3. Wetland Restoration and Biodiversity Conservation

Restoration of degraded wetlands not only improves carbon storage but also enhances biodiversity. Biodiversity in wetlands encompasses a wide range of species, including macrophytes, fish, amphibians, birds, and invertebrates. Restoration activities—such as re-establishing hydrological regimes, replanting native vegetation, and removing invasive species—create conditions conducive to the return of native species and the recovery of ecological functions. For instance, restoration activities in the East Kolkata Wetlands demonstrated improved macrophyte diversity, enhanced carbon inputs through vegetation, and increased habitat availability for fish and migratory birds [6].

The Ramsar-designated wetlands of India, currently numbering 91, are crucial for migratory birds and endemic aquatic flora and fauna. However, many of these wetlands face threats from eutrophication, encroachment, and unregulated tourism. Restoration efforts, including pollution abatement and rehydration measures, have led to observable increases in bird populations and vegetation cover in several Ramsar sites. Despite these positive outcomes, biodiversity responses to restoration can vary. While species richness often recovers quickly, functional diversity—representing ecological roles such as nutrient cycling or seed dispersal—may take longer to reestablish.

4. Restoration Practices, Policies, and Implementation in India

Wetland restoration in India operates under multiple policy frameworks, including the Wetlands (Conservation and Management) Rules, the National Biodiversity Action Plan, and India's Nationally Determined Contributions (NDCs) under the Paris Agreement. The Ministry of Environment, Forest and Climate Change (MoEF&CC) and organizations such as Wetlands International South Asia play leading roles in implementing these programs. The Indo-German Biodiversity Programme has recently emphasized integrating wetland restoration into India's climate mitigation agenda [7].

Restoration techniques in India typically focus on restoring hydrological conditions, replanting native vegetation, and controlling pollution. Hydrological restoration ensures the maintenance of natural inflows and outflows essential for wetland health. Vegetative restoration involves planting native species, including mangroves and aquatic macrophytes, while removing invasive species that alter nutrient cycles. Pollution control measures, such as treating sewage inflows and managing catchment runoff, are also vital. Successful restoration often requires active community participation, particularly in rural India, where local communities rely on wetlands for livelihoods such as fishing and fodder collection.

Empirical case studies illustrate these points. The Timbi Reservoir in Gujarat demonstrated carbon storage of about 76.2 tons per hectare in the top 15 cm of sediment, with higher organic carbon stocks in areas under longer inundation [8]. Similarly, Rudrasagar Lake in Tripura showed spatial variations in carbon storage depending on depth and vegetation cover, suggesting the importance of localized hydrological management [9]. These examples underscore how scientifically guided restoration can yield measurable carbon and biodiversity gains.

5. Challenges and Knowledge Gaps

Wetland restoration in India faces numerous challenges. A major limitation is the lack of long-term monitoring data on carbon fluxes and biodiversity responses. Many restoration projects focus on short-term vegetation recovery rather than long-term ecosystem functioning. Temporal stability of carbon pools remains uncertain, particularly because wetlands can also emit methane—a potent greenhouse gas—depending on hydrological conditions and organic matter decomposition rates. Wetlands across India vary widely in size, hydrology, and biogeochemical conditions, making it difficult to generalize findings or design uniform restoration protocols. Furthermore, policy fragmentation, overlapping jurisdictions, and limited funding hinder large-scale implementation.

Biodiversity monitoring often emphasizes species counts rather than functional or genetic diversity, leading to incomplete assessments of restoration success.

Social and institutional issues also impede progress [10]. Many wetlands are located on common or disputed lands, leading to conflicts among local users, developers, and government agencies. Capacity building and clear institutional mandates are urgently needed to overcome these barriers.

6. Integration with National Climate and Biodiversity Goals

Wetland restoration can make a significant contribution to India's commitments under the Paris Agreement [11]. wetlands support India's target of creating additional carbon sinks through forest and ecosystem restoration. Furthermore, restored wetlands enhance resilience to floods and droughts, aligning with adaptation priorities. Incorporating wetland carbon accounting into national greenhouse gas inventories and carbon market mechanisms could unlock new funding streams for restoration.India's National Biodiversity Strategy and Action Plan also recognizes wetlands as priority ecosystems for conservation. Yet, stronger integration between biodiversity and climate policies is required [12]. The inclusion of freshwater wetlands within India's carbon credit frameworks—alongside forests and mangroves—would provide both financial incentives and conservation co-benefits. International conventions such as Ramsar can further facilitate knowledge exchange and access to restoration funds.

7. Future Directions and Recommendations

Future wetland restoration in India should prioritize scientifically informed, community-driven, and policy-supported approaches. Standardized protocols for measuring carbon stocks, greenhouse gas fluxes, and biodiversity recovery should be developed to ensure comparability across sites. Non-tidal freshwater wetlands, which have been underrepresented in carbon accounting, deserve greater attention in both research and restoration efforts. Restoration programs should not only focus on species richness but also on restoring ecological functions and connectivity among wetland systems.Ensuring hydrological integrity must remain central to all restoration initiatives, as water regime alterations are often the primary cause of wetland degradation. Strengthening policy coherence, integrating financial incentives such as carbon credits, and enforcing existing protection laws are essential steps forward. Above all, involving local communities and incorporating traditional ecological knowledge can significantly improve restoration outcomes and ensure long-term sustainability.

8. Conclusion

Wetland restoration in India represents a powerful nature-based solution for addressing climate change and biodiversity loss. Evidence from across the country demonstrates that restored wetlands—both inland and coastal—can store substantial carbon stocks while supporting diverse biological communities. Yet, challenges persist in the form of limited monitoring, policy gaps, and socio-economic constraints. By integrating restoration science with participatory governance and national climate policies, India can unlock the full potential of its wetlands as engines of carbon sequestration and biodiversity conservation. The time is ripe for a renewed, evidence-based approach that recognizes wetlands not as wastelands but as vital ecosystems essential for ecological balance and sustainable development.

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