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Editorial Choice



MUMBAI'S MANGROVES AT A CROSSROADS

DEVELOPMENT, CLIMATE RISK, AND THE ECOLOGICAL COST OF COASTAL ROADS

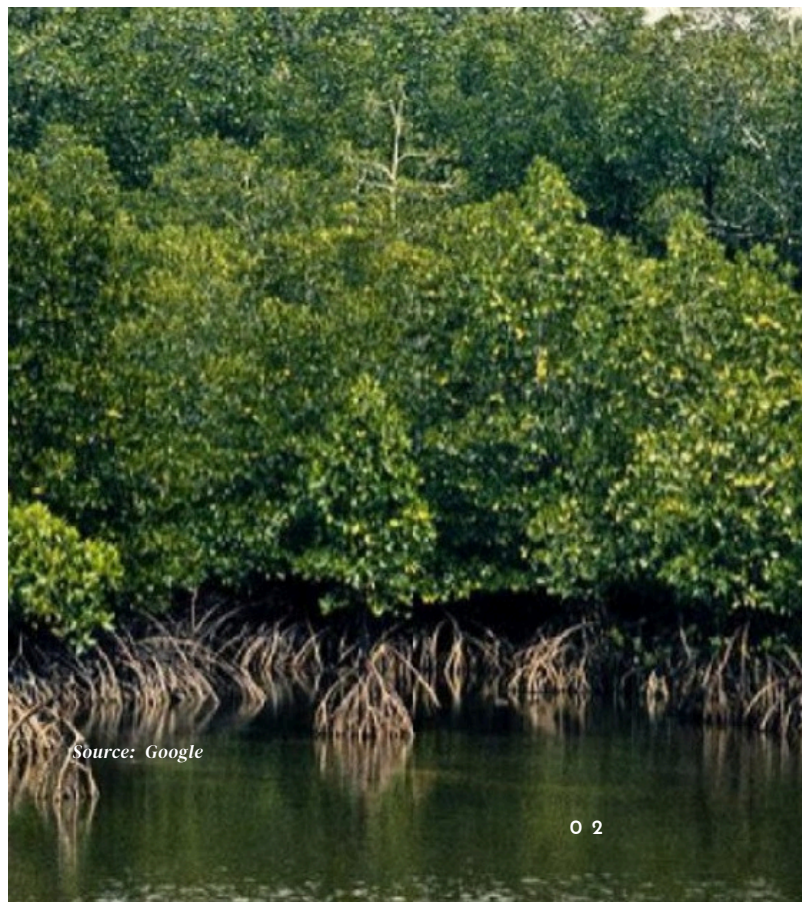
Ms. Anolita Singho, Communication Officer (PFRI)

Mumbai's identity is inseparable from its coastline. The city's growth, economy, and culture have unfolded along the edge of the Arabian Sea, even as this geography exposes it to rising climate risks. Sea-level rise, extreme monsoon rainfall, tidal flooding, and storm surges are no longer future threats but present challenges (IPCC, 2023). In this context, decisions about coastal infrastructure carry consequences that extend far beyond mobility and economic efficiency. The recent decision of the Bombay High Court permitting the removal of over 45,000 mangrove trees for the Versova - Bhayander Coastal Road has placed Mumbai at the center of a critical national debate. While the project is framed as a necessary development intervention, scientists, environmental planners, and civil society groups warn that the ecological costs may significantly undermine the city's long-term climate resilience.

The Coastal Road Proposal

The Versova-Bhayander Coastal Road is a proposed 26-kilometre corridor along Mumbai's western coastline, intended to improve north-south connectivity across the Mumbai Metropolitan Region. The Brihanmumbai Municipal Corporation (BMC) argues that the project will reduce travel time, ease traffic congestion, and enhance economic connectivity.

After reviewing statutory environmental clearances and mitigation measures, the Bombay High Court approved the diversion of mangrove forest land along the project alignment. This approval allows for the felling of approximately 45,000 mangrove trees, subject to conditions such as compensatory afforestation, long-term ecological monitoring, and periodic compliance reporting. Although legally sanctioned, the decision raises fundamental scientific and policy questions about how coastal cities should balance infrastructure development with climate adaptation.



Source: Google

Why Mangroves Matter

Mangroves are among the most ecologically valuable coastal ecosystems on Earth. A substantial body of scientific research shows that mangroves act as natural buffers against storm surges and cyclones, reduce coastal erosion by stabilizing sediments, and significantly lower flood impacts during extreme weather events (Alongi, 2008; Das & Vincent, 2009).

Mangroves also serve as critical nursery habitats for fish and invertebrates, supporting coastal fisheries and livelihoods, while storing large quantities of carbon in their biomass and soils. This 'blue carbon' function makes mangroves highly effective nature-based solutions for climate mitigation (Donato et al., 2011).

In Mumbai, mangroves function as natural infrastructure. They regulate tidal flows, absorb excess rainwater, and support drainage in low-lying areas. Past flood events, particularly the catastrophic floods of 2005, have demonstrated how the loss of wetlands and mangroves can intensify urban flooding and disruption (MGGM disaster assessments, n.d.).

Compensatory Afforestation: An Incomplete Solution

A central justification for permitting mangrove diversion lies in compensatory afforestation commitments. Authorities have pledged to plant several times the number of mangroves removed, often in districts outside Mumbai. Ecological science, however, cautions against treating compensatory plantations as equivalent substitutes for natural mangrove systems. Mangroves are highly site-specific ecosystems that depend on precise tidal inundation, salinity gradients, sediment supply, and hydrological connectivity (Friess et al., 2019).

Plantations established outside natural creek systems frequently show low survival rates and limited ecological functionality. Even where plantations succeed, it can take decades for young mangroves to provide levels of coastal protection comparable to mature forests. Studies on restoration outcomes consistently show that recreated mangrove habitats rarely match the ecological performance of natural systems in the short to medium term (Lewis, 2005).

Development Versus Resilience: A False Choice

The debate surrounding Mumbai's coastal road is often framed as a trade-off between development and environmental protection. Increasingly, global research challenges this framing. Cities across the world are recognizing that degrading natural ecosystems leads to higher long-term economic costs by increasing disaster risk and climate vulnerability. Nature-based solutions are now central to urban adaptation strategies, complementing engineered infrastructure rather than competing with it (World Bank, 2021).

In Mumbai's context, urban planners and climate researchers question whether car-centric coastal roads align with sustainable development goals, particularly when public transport expansion, wetland conservation, and integrated coastal zone management could deliver broader and more resilient outcomes.

Legal Safeguards and Implementation Gaps

The Bombay High Court imposed several safeguards, including a three-to-one compensatory plantation requirement, ten years of ecological monitoring, and annual reporting on survival and compliance.

On paper, these measures represent an effort to balance development with environmental protection. However, India's experience with compensatory afforestation has shown mixed results. Reviews by environmental agencies and researchers point to challenges such as inadequate site selection, weak enforcement, limited transparency, and insufficient long-term monitoring (CAG reports; MoEFCC reviews, n.d.). Without independent scientific oversight and public accountability, safeguards risk becoming procedural rather than protective.

Broader Implications

The implications of this decision extend beyond Mumbai. Coastal cities across India and the Global South face similar pressures as urban expansion intersects with climate vulnerability. Key questions emerge: How should policymakers weigh short-term infrastructure gains against long-term climate risks? Can compensatory plantations replace site-specific ecosystems? Who bears the social and economic costs when ecological degradation amplifies flooding, heat stress, and public health risks?

As climate change accelerates, these questions will increasingly shape urban governance and environmental jurisprudence.

A Moment for Reflection

The removal of 45,000 mangroves is not merely a local planning issue; it reflects how societies value ecological systems under development pressure. Scientific consensus is clear: nature is not an obstacle to progress but a foundation for resilient cities.

For Mumbai, the choices made today will shape its ability to withstand future climate extremes. Ensuring that infrastructure development is informed by ecological science, climate risk assessment, and ethical governance is essential.

At the Progyan Foundation for Research and Innovation, we believe that informed public dialogue grounded in science and policy analysis is critical for sustainable futures. In cases such as Mumbai, coastal infrastructure decisions should be guided by the principle that climate resilience is not a secondary environmental concern but a core criterion of urban planning. We further believe that ecologically sensitive urban regions require more transparent and participatory decision-making, particularly where the long-term public costs of ecosystem loss may outweigh immediate project benefits. Mumbai's mangroves stand as a living test of whether cities choose short-term convenience or long-term resilience.



Source: Communication Department, PFRI

References

- Alongi, D. M. (2008). Mangrove forests: Resilience, protection from tsunamis, and responses to global climate change. *Estuarine, Coastal and Shelf Science*, 76(1), 1–13
<https://doi.org/10.1016/j.ecss.2007.08.024>
- Comptroller and Auditor General of India. (2013). *Report No. 21 of 2013: Compliance audit on compensatory afforestation in India (Union Government, Ministry of Environment and Forests)*. Government of India.
- Comptroller and Auditor General of India. (2024). *Report No. 5 of 2024: Performance audit on functioning of Compensatory Afforestation Fund Management and Planning Authority (for the year ended 31 March 2022)*. Government of Uttarakhand.
- Comptroller and Auditor General of India. (2024). *Report No. 3 of 2024: Performance audit on compensatory afforestation in Himachal Pradesh*. Government of Himachal Pradesh.
- Das, S., & Vincent, J. R. (2009). Mangroves protected villages and reduced death toll during the 2004 Indian Ocean tsunami. *Proceedings of the National Academy of Sciences of the United States of America*, 106(18), 7357–7360. <https://doi.org/10.1073/pnas.0810440106>
- Donato, D. C., Kauffman, J. B., Murdiyarso, D., Kurnianto, S., Stidham, M., & Kanninen, M. (2011). Mangroves among the most carbon-rich forests in the tropics. *Nature Geoscience*, 4, 293–297. <https://doi.org/10.1038/ngeo1123>
- Friess, D. A., Rogers, K., Lovelock, C. E., Krauss, K. W., Hamilton, S. E., Lee, S. Y., Lucas, R., Primavera, J., Rajkaran, A., and Shi, S. (2019). The state of the world's mangrove forests: Past, present, and future. *Annual Review of Environment and Resources*, 44, 89–115
<https://doi.org/10.1146/annurev-environ-101718-033302>
- Intergovernmental Panel on Climate Change. (2023). *Climate change 2022: Impacts, adaptation and vulnerability (Sixth Assessment Report)*. Cambridge University Press
- Lewis, R. R. (2005). Ecological engineering for successful management and restoration of mangrove forests. *Ecological Engineering*, 24(4), 403–418
<https://doi.org/10.1016/j.ecoleng.2004.10.003>
- Municipal Corporation of Greater Mumbai. (2006). *Mumbai floods 2005: Disaster assessment and response report*. Government of Maharashtra
- Ministry of Environment, Forest and Climate Change. (Various years). *Compensatory Afforestation Fund Management and Planning Authority (CAMPA) annual reports*. Government of India.
- National Compensatory Afforestation Fund Management and Planning Authority. (2019). *Annual report 2018–19*. Ministry of Environment, Forest and Climate Change, Government of India.
- National Compensatory Afforestation Fund Management and Planning Authority. (2020). *Annual report 2019–20*. Ministry of Environment, Forest and Climate Change, Government of India.
- National Compensatory Afforestation Fund Management and Planning Authority. (2021). *Annual report 2020–21*. Ministry of Environment, Forest and Climate Change, Government of India.
- National Compensatory Afforestation Fund Management and Planning Authority. (2022). *Annual report 2021–22*. Ministry of Environment, Forest and Climate Change, Government of India.
- National Compensatory Afforestation Fund Management and Planning Authority. (2023). *Annual report 2022–23*. Ministry of Environment, Forest and Climate Change, Government of India.
- National Compensatory Afforestation Fund Management and Planning Authority. (2024). *Annual report 2023–24*. Ministry of Environment, Forest and Climate Change, Government of India.
- World Bank. (2021). *Nature-based solutions for coastal resilience*. World Bank Group.

Current Context



TRANSBOUNDARY WETLAND GOVERNANCE IN SOUTH ASIA:

PROGRESS, GAPS, AND INSTITUTIONAL LIMITS

Dr. Chandreyi Sengupta, Senior Research Officer (PFRI)

Wetland ecosystems constitute some of the most socio-ecologically significant landscapes in South Asia. They regulate hydrological processes, sustain biodiversity, support fisheries and agriculture, and fortify the livelihoods of large populations across river basins, deltas, and coastal zones. Despite this importance, wetlands across the region continue to experience degradation through land conversion, altered river flows, pollution, and climate-related pressures. Recent global assessments indicate that wetland loss has continued over the past decades, even as international policy frameworks have expanded their emphasis on restoration and sustainable management. This divergence between ecological decline and policy ambition forms the central context within which regional cooperation in South Asia must be understood (CoW, 2025).

The need for cooperative governance arises from the inherently transboundary nature of many South Asian wetland systems. Major river basins such as the Ganges, Brahmaputra, and Indus traverse multiple national jurisdictions, while coastal and deltaic wetlands are shaped by shared sediment flows, tidal regimes, and climatic influences. Migratory species further reinforce ecological interdependence across borders. Under such conditions, conservation strategies confined to individual sites or national boundaries are mostly unproductive. Effective management requires mechanisms that can address shared ecological processes, harmonise data systems, and enable coordinated responses to common pressures (Penniman et al., 2025).



Source: Communication Department, PFRI

In recent years, multilateral frameworks have sought to strengthen transboundary cooperation. The Convention on Wetlands has increasingly emphasised restoration, integration with climate and biodiversity agendas, and the role of regional collaboration. One of the principal instruments through which this is being pursued is the system of Ramsar Regional Initiatives. These initiatives are designed to facilitate cooperation among countries within a defined geographical context, with a focus on knowledge exchange, capacity development, and improved implementation of wetland-related commitments. Developments at the fifteenth meeting of the Conference of the Parties in 2025 reaffirmed the importance of such mechanisms, including the advancement of the Indo-Burma regional initiative and ongoing discussions on a broader platform for South Asia (Penniman et al., 2025).

The potential contribution of these arrangements is significant. Regional initiatives can provide a structured platform for sharing technical expertise, aligning aspects of policy language, and strengthening monitoring and reporting practices. They can also support the development of inventories and facilitate collaboration among national focal points, research institutions, and conservation agencies. In a region where hydrological systems and ecological processes are interconnected, such coordination is essential for addressing cumulative impacts that extend beyond political boundaries. However, the institutional landscape remains uneven. The emerging regional architecture is still in a formative stage, and coverage is not comprehensive across South Asia.

Existing initiatives do not yet encompass all relevant countries or wetland systems, and proposed mechanisms are still undergoing negotiation and design. This incomplete institutionalisation is notable given the scale of the ecological challenge. While the policy discourse increasingly recognises the importance of cooperation, the operational frameworks required to sustain it are not yet fully consolidated.

The Sundarban provides a useful illustration of both progress and limitation. Although Bangladesh listed its part of the mangrove wetland under the Ramsar Convention in 1992 and India followed in 2019, the two sides continue to be managed through separate national systems rather than through a unified cross-border regime. Recent published evidence continues to identify coordination problems between the two countries and calls for stronger cross-border governance, interconnected policy design, and greater attention to local knowledge in adaptation and management. This is significant because the ecological pressures affecting the delta, including salinity change, cyclones, erosion, and development pressure, do not stop at the border. In practical terms, the key governance problem here is not the absence of recognition, but the absence of a sufficiently durable bilateral mechanism capable of moving from parallel management to genuinely shared planning (Dutta et al., 2026). The Koshi River floodplain along the Nepal-India border illustrates a different but equally significant problem of transboundary wetland governance. In this case, the central weakness lies in the fragmentation of authority across multiple institutions and across international boundaries, which undermines coordinated management.

Research on the Koshi has shown that flood management remains weak, particularly following the 2008 flood, due to poor institutional coordination and a complex organisational structure (Acharya & Hori, 2009).

These two cases together demonstrate a broader structural pattern across South Asia- where transboundary wetland systems exist, governance responses tend to be either formally recognised but operationally parallel, or institutionally fragmented across competing authorities. In neither instance has recognition alone translated into the sustained coordinated management that ecological realities demand. Closing this gap requires targeted interventions that go beyond declaratory commitments. At the bilateral level, countries sharing transboundary wetland systems should be encouraged to establish standing joint technical committees with defined mandates, regular meeting cycles, and shared data protocols. Such mechanisms need not await comprehensive political agreements; functional cooperation on monitoring, early warning for floods, and species migration can proceed incrementally, building the institutional trust necessary for deeper coordination over time.

At the regional scale, the focus ought to be on bringing in countries and ecosystems currently peripheral to these frameworks, supported by long-term investment in capacity. Ultimately, the credibility of regional cooperation rests less on the sophistication of the frameworks designed than on whether those frameworks produce demonstrable improvements in the monitoring, management, and protection of shared wetland systems, a test that, across much of South Asia, remains largely unmet.

References

- Acharya, S., & Hori, T. (2019). Revisiting flood management process in transboundary Koshi River in Nepal and India. *DPRI Annuals (Kyoto University Disaster Prevention Research Institute Annuals)*, 62(B), 640–649
- Convention on Wetlands. (2025). *Global Wetland Outlook 2025: Valuing, conserving, restoring and financing wetlands*. Secretariat of the Convention on Wetlands. <https://doi.org/10.69556/GWO-2025-eng>
- Dutta, S., Das, S., Gorain, S., Kundu, S., Bera, M., Roy Choudhury, M., Bag, S., & Das, D. P. (2026). Unraveling anthropogenic and climate stressors in the Sundarbans and their ripple effects on livelihoods and ecosystems, and adaptation strategies for a sustainable future – A systematic review. *Environmental Development*, 58, 101410. <https://doi.org/10.1016/j.envdev.2025.101410>
- Penniman, T., Fernandez, C., Kinniburgh, F., Munda, C., & Willetts, L. (2025). *Summary of the fifteenth meeting of the Conference of the Contracting Parties to the Ramsar Convention on Wetlands: 24–31 July 2025* (Earth Negotiations Bulletin, Vol. 17, No. 61). International Institute for Sustainable Development. <https://enb.iisd.org/ramsar-convention-wetlands-cop15>



CAN KOLKATA'S VARIEGATED PERIPHERIES SURVIVE MUNICIPALIZATION?

Mr. Rajib Das, Research Assistant (PFRI)

Kolkata's east and southern fringes show how urbanization proceeds through regulatory gaps: rural panchayat rules fade before municipal law fully arrives, creating variegated peripheries where wetlands and ponds are casually filled to make land for real estate. Around Joka and the East Kolkata Wetlands (EKW), this in-between time is not empty of power; it is dense with overlapping and negotiable governance.

Peri-urban Kolkata is legally “rural” but materially urban, governed by gram panchayats that lack mandate and capacity for fast, infrastructure-driven growth (Mondal & Banerjee, 2021; Mondal & Sen, 2020). The Nagar Panchayat category, intended for such transitions, is largely not implemented in West Bengal, leaving expanding urban settlements under weak rural self-government (Mondal & Banerjee, 2021; Mondal & Sen, 2020; Butsch et al., 2021). Municipal boundaries remain static for decades and are re-drawn selectively, as in the 2012 incorporation of Joka I and II into Kolkata Municipal Corporation while adjacent panchayats were left out, despite similar urban pressures (Mondal & Sen, 2020).

This produces fragmented, overlapping regimes where rural panchayats, line departments and future municipal actors coexist, but no single authority clearly regulates land and water, especially ponds and wetlands (Butsch et al., 2021; Gomes et al., 2023).

In this institutional interstice, enforcement is negotiable, and pond-filling becomes routinized rather than exceptional.

In the EKW, proximity to Kolkata's growth front has driven rapid shrinkage and fragmentation of wetland waterscapes under unplanned development and infrastructural encroachment (Mondal et al., 2017; Haque, 2020; Mondal et al., 2022; Roy-Basu et al., 2020). Urban sprawl, real estate projects and transport corridors convert low-value wet or agricultural land into commodified “urban” land, often by illegally filling wetlands and ponds (Sawyer et al., 2021; Huque et al., 2020; Pakrashi, 2021).

“Bypass urbanism” captures this—large ensembles of projects at the periphery, enabled by state infrastructure (bypass roads, metro) and exploited by private actors who capitalize on regulatory ambiguity to encroach into wetlands and waterbodies (Sawyer et al., 2021; Huque et al., 2020). In peri-urban Kolkata, weak panchayat governance and not-yet-active municipal regimes form precisely the variegated terrain where this bypassing of environmental law occurs (Mondal & Banerjee, 2021; Butsch et al., 2021; Gomes et al., 2023). Wetlands and ponds at Kolkata's edge perform critical ecosystem functions, sewage treatment, flood buffering, groundwater recharge, yet remain largely invisible in metropolitan planning,

from long-term perspective plans to sectoral strategies (Huque et al., 2020; Mukherjee et al., 2021; Paul & Bardhan, 2023). Peri-urban wetlands contribute over half of Kolkata's water-related ecosystem service value, even as their area declines and surface-water quality deteriorates under expanding settlements (Mukherjee et al., 2021; Yadav et al., 2024; Roy-Basu et al., 2020).

These waterscapes also sustain peri-urban poor through fishing, farming and waste recycling; encroachment and pond-filling thus dispossess livelihoods while eroding ecological security (Pakrashi, 2021; Roy-Basu et al., 2020; Mukherjee et al., 2021). A mosaic of formal statutes (Ramsar designation, wetland protection acts) and informal practices (customary use, ad-hoc deals) co-produces an uneven regulatory surface where conservation is invoked but rarely enforced in the peri-urban zone (Roy-Basu et al., 2020; Mukherjee, 2022; Mukherjee et al., 2021; Butsch et al., 2021).

Kolkata's peri-urban pondscape are not being lost in a legal vacuum but in variegated peripheries where panchayat rule, deferred municipalization and fragmented sectoral agencies collide. In this overlap, pond and wetland filling becomes normalized, enabling bypass urbanism and silently restructuring hydrosocial relations and urban risk. Any serious response must treat these peripheries as core urban territory, politically, juridically and ecologically, rather than as expendable, "not-yet-city" margins.



References

- Butsch, C., Chakraborty, S., Gomes, S., Kumar, S., & Hermans, L. (2021). Changing Hydrosocial Cycles in Periurban India. *Land*. <https://doi.org/10.3390/land10030263>
- Gomes, S., Hermans, L., Chakraborty, S., Luft, S., Butsch, C., & Banerjee, P. (2023). Comparative analysis of local adaptation processes in the future across peri-urban India to support transformations to sustainability. *Global Environmental Change*. <https://doi.org/10.1016/j.gloenvcha.2023.102721>
- Haque, S. (2020). Assessing Infrastructural Encroachment and Fragmentation in the East Kolkata Wetlands. **, 233-257. https://doi.org/10.1007/978-3-030-35237-0_13
- Huque, S., Pattanaik, S., & Parthasarathy, D. (2020). Cityscape Transformation and the Temporal Metamorphosis of East Kolkata Wetlands: A Political Ecology Perspective. *Sociological Bulletin*, 69, 112 - 95. <https://doi.org/10.1177/0038022919899020>
- Mondal, B., Dolui, G., Pramanik, M., Maity, S., Biswas, S., & Pal, R. (2017). Urban expansion and wetland shrinkage estimation using a GIS-based model in the East Kolkata Wetland, India. *Ecological Indicators*, 83, 62-73. <https://doi.org/10.1016/j.ecolind.2017.07.037>
- Mondal, D., & Sen, S. (2020). Methodological Dimensions of Delineating Peri-urban Areas: The Case of Kolkata Metropolis. *Environment and Urbanization Asia*, 11, 183 - 194. <https://doi.org/10.1177/0975425320938519>
- Mondal, D., & Banerjee, A. (2021). Exploring peri-urban dynamism in India: Evidence from Kolkata Metropolis. *Journal of Urban Management*. <https://doi.org/10.1016/j.jum.2021.06.004>
- Mondal, B., Kumar, S., Ghosh, A., & Mishra, P. (2022). Transformation and Risk Assessment of East Kolkata Wetlands (India) using Fuzzy MCDM Method and Geospatial Technology. *Geography and Sustainability*. <https://doi.org/10.1016/j.geosus.2022.07.002>
- Mukherjee, S., Sikdar, P., Pal, S., & Schütt, B. (2021). Assessment of Environmental Water Security of an Asian Deltaic Megacity and Its Peri-Urban Wetland Areas. *Sustainability*. <https://doi.org/10.3390/su13052772>
- Mukherjee, J. (2022). “Living systems infrastructure” of Kolkata: exploring co-production of urban nature using historical urban political ecology (HUPE). *Environment & Urbanization*, 34, 32 - 51. <https://doi.org/10.1177/09562478221084560>
- Pakrashi, H. (2021). The peri-urban poor and ecology in the megacity of Kolkata. *Urbanization in the Global South*. <https://doi.org/10.4324/9781003093282-13>
- Paul, S., & Bardhan, S. (2023). Landscapes to eco-scapes: prescriptive transitions for urban waterways for an Indian megacity. *Urban Water Journal*, 20, 1361 - 1374. <https://doi.org/10.1080/1573062x.2022.2086883>
- Roy-Basu, A., Bharat, G., Chakraborty, P., & Sarkar, S. (2020). Adaptive co-management model for the East Kolkata wetlands: A sustainable solution to manage the rapid ecological transformation of a peri-urban landscape.. *The Science of the total environment*, 698, 134203. <https://doi.org/10.1016/j.scitotenv.2019.134203>
- Sawyer, L., Schmid, C., Streule, M., & Kallenberger, P. (2021). Bypass urbanism: Re-ordering center-periphery relations in Kolkata, Lagos and Mexico City. *Environment and Planning A: Economy and Space*, 53, 675 - 703. <https://doi.org/10.1177/0308518x20983818>
- Yadav, P., Jha, P., Joy, M., & Bansal, T. (2024). Ecosystem health assessment of East Kolkata Wetlands, India: Implications for environmental sustainability.. *Journal of environmental management*, 366, 121809. <https://doi.org/10.1016/j.jenvman.2024.121809>

FROM TRADITION TO TRANSFORMATION:

INDIGENOUS COMMUNITIES, CHANGING LIVELIHOODS, AND ENVIRONMENTAL CONFLICT OF GRASSLAND ECOSYSTEM IN INDIA

Mr. Sujay Bhattacharjee, Research Assistant (PFRI)

The tribal people are the initial dwellers in India. They are commonly designated as Adivasi the original settlers, Girijan the hill dwellers, Vanyaajati the forest caste, Adimjati the primitive castes, Jana Jati the folk communities, Anusuchit Jan Jati the schedule tribes and they live in different parts of India, commonly known as Adivais for tribal people (Sahoo 2024). Indigenous tribes in Indian grasslands are original inhabitants who maintain a close, sustainable relationship with their natural environment through traditional practices that support biodiversity, cultural identity, and livelihoods. These tribal communities often live in forests, hills, and isolated areas where they rely on nature-friendly methods for agriculture, medicine, and resource use, contributing to long-term ecological balance and social harmony (Sahoo 2024; Priyadarshini et al. 2019). India possesses a diverse array of grassland ecosystems, which are critical for biodiversity conservation, ecosystem services, and the livelihoods of local communities, despite often being undervalued and poorly managed (Avishek et al., 2021; Mande et al., 2025; Lahiri et al, 2023). These grasslands face significant threats from anthropogenic activities and environmental changes (Avishek et al., 2021; Mande. et al., 2025).

Some important grassland types and regions in India include: The Thar Desert of Rajasthan, particularly in the districts of Jaisalmer, Jodhpur, and Bikaner, supports some of India's most significant remaining grassland ecosystems. These arid landscapes serve as critical habitats for globally threatened species such as the Great Indian Bustard, Houbara bustard, and blackbuck (Islam, et al, 2011). Similarly, the Banni grasslands of Kachchh in Gujarat-Asia's largest tropical grassland-provide essential ecological functions and sustain distinctive biodiversity (Dey, et al, 2024). Despite their importance, these ecosystems face increasing pressure from population growth, agricultural expansion, and developmental interventions, resulting in habitat degradation and fragmentation. Notably, the Banni grasslands remain largely unprotected and are often misclassified as 'wastelands,' undermining their ecological value (Samrat, et al, 2021).



Source: Freepik

The Terai-Duar Savanna and Grassland ecoregion, located along the Himalayan foothills of the Indian subcontinent, comprises a mosaic of grasslands, savannas, and forests (Banerjee, et al, 2023). Once extensive, its characteristic tall grasslands are now largely confined to fragmented patches within protected areas of lowland close to Nepal and northern India (Peet, et al., 1999). These ecosystems harbor high levels of endemism, making their decline a serious concern for biodiversity and ecosystem functioning. Over recent decades, significant grassland loss has been documented, primarily driven by woody encroachment. For instance, landscape-level studies in northeastern Uttar Pradesh have recorded substantial plant diversity within Terai grasslands, with up to 287 species identified (Srivastava., et al., 2016). Strengthened conservation efforts in these sub-Himalayan grasslands are therefore critical for their long-term sustainability.

The Western and Kashmir Himalayan regions host vital alpine and mid-altitude grasslands that support key ecosystem services, including carbon storage, food production, and livestock grazing. However, these ecosystems are highly threatened by land-use change, agricultural intensification, land abandonment, and climate change (Pandey, et al., 202; Saha, et al., 2024).

The Deccan Plateau of Peninsular India supports ecologically significant grasslands that contribute to biodiversity conservation and livestock forage. Despite their importance, these ecosystems have historically been misclassified as ‘wastelands,’ limiting their policy recognition and protection (Padbhushan, et al., 2020). They harbor a high degree of endemism, particularly among grass species such as those of the Andropogoneae tribe (Mehrotra, et al, 2024). Notably, the Amrit Mahal Kaval grasslands in Karnataka serve both biodiversity conservation and the preservation of indigenous cattle breeds (Ashwatha, 2020). Emerging studies further underscore the role of these grasslands in carbon storage and soil health, highlighting their ecological significance.

More broadly, India’s 705 Scheduled Tribe communities include many groups whose livelihoods are intertwined with grasslands, forests, and savanna-like ‘forest-grassland mosaics,’ particularly through pastoralism, shifting cultivation, and NTFP collection (Ballabh, 2024; Joshi, et al., 2018).

In the Thar Desert of Rajasthan, major tribal communities include the Bhil, Mina, Sahariya, Garasia, Damor, and Kathodi, (Bhasin, et al., 2007; Shrivastava, et al., 2001) primarily concentrated along the Aravalli Range across districts such as Alwar, Banswara, Baran, Chittorgarh, Dungarpur, Sawai Madhopur, Sirohi, and Udaipur. The Bhil, one of India’s largest tribal groups, are distributed across Rajasthan, Madhya Pradesh, Gujarat, and Maharashtra, while the Sahariya are largely confined to remote forested tracts of southeastern Rajasthan (Rastogi, 2024).



In Gujarat, tribal populations are concentrated in districts such as Panchmahal, Dahod, Chhota Udaipur, Mahisagar, and Vadodara, with prominent groups including the Rathwa, Tadvi, Nayaka–Naykada, Bhil, Patelia, and Vasava. Additionally, the Rann of Kutch hosts distinct ethnic communities adapted to saline desert conditions along the western coastal margin (Chaudhari, 2022). In extent, the Western Ghats and Nilgiri Hills shola, grassland mosaics, the Toda pastoralists are prominent, alongside other Scheduled Tribe groups such as Soliga, Kadu Kuruba, Jenu Kuruba, Irula (Iruliga), Kattunayaka, Paniyan, Adiyar, and Koraga. In the Spiti Valley of the Trans-Himalaya, the Kibber community represents a key agro-pastoral system dependent on alpine grasslands. In the Eastern Himalaya, particularly Arunachal Pradesh, tribal groups such as Nyishi, Adi, and Monpa are notable, while in the Barind Region, various tribal communities depend on grass-dominated landscapes for subsistence.

Approximately 12-15 million hectares, or 3-7% of India's total geographical area, have historically been recorded as permanent pasture or grazing land. However, this land is rapidly being lost to expanding agriculture, overstocking of domestic animals, improper management, lack of quantitative spatiotemporal information (Jadhav et al., 1993; Paul, et al, 2023).

Indigenous communities in Indian grassland ecosystems are experiencing significant transformations in their livelihoods due to environmental changes, development pressures, and policy shifts. Many tribes practice shifting agriculture, which remains vital for food security, cultural heritage, and biodiversity but faces challenges from climate change impacts such as soil degradation, crop loss, and reduced land fertility (Hazarika, et al, 2024; Sharma, 2024). Adaptive strategies include agricultural diversification toward high-value crops and agroforestry, which help improve economic returns while maintaining ecological balance (Hazarika, et al, 2024). Indigenous governance systems in regions like the Trans-Himalaya demonstrate complex, inclusive decision-making that supports sustainable ecosystem service management despite social inequities (Murali, et al., 2022). However, expanding protected areas and industrial development often restrict Indigenous land rights and access to natural resources, leading to conflicts and livelihood losses (Vijayan, et al, 2021).

Strengthening traditional knowledge systems and meaningfully including Indigenous perspectives in conservation and development policies is essential for building resilience and ensuring the long-term sustainability of both ecosystems and tribal livelihoods in the face of environmental and social challenges.



References

- Sahoo, P. (2024). Practices of Indigenous People are Leading Towards Sustainability. *International Journal For Multidisciplinary Research*. <https://doi.org/10.36948/ijfmr.2024.v06i01.12268>.
- Priyadarshini, P., & Abhilash, P. (2019). Promoting tribal communities and indigenous knowledge as potential solutions for the sustainable development of India. *Environmental development*, 32, 100459. <https://doi.org/10.1016/j.envdev.2019.100459>.
- Avishek, K., & Kumar, A. (2021). Environmental Hazards Due to Grassland Ecosystem Degradation: Perspectives on Land Management in India. In *Earth and Environmental Sciences Library* (pp. 363–376). Springer International Publishing. https://doi.org/10.1007/978-3-030-76116-5_20
- Mande, M., Joshi, A. A., Paramjyothi, H., Ratnam, J., & Sankaran, M. (2025). Patterns of grass (Poaceae) species distribution and richness across India. *Global Ecology and Conservation*, 62, e03741. <https://doi.org/10.1016/j.gecco.2025.e03741>
- Lahiri, S., Roy, A., & Fleischman, F. (2023). Grassland conservation and restoration in India: a governance crisis. *Restoration Ecology*, 31(4). <https://doi.org/10.1111/rec.13858>
- Islam, M. Z., & Rahmani, A. R. (2011). Thar Desert, Rajasthan, India: anthropogenic influence on biodiversity and grasslands. *Biodiversity*, 12(2), 75–89. <https://doi.org/10.1080/14888386.2011.585931>
- Dey, R., Sharma, S. B., & Thakkar, M. G. (2024). Maximising ecological value and assessing land suitability for sustainable grassland management in Asia's largest tropical grassland, Western India. *Scientific Reports*, 14(1). <https://doi.org/10.1038/s41598-024-62775-9>
- Samrat, A., Devy, M. S., & Ganesh, T. (2021). Delineating fragmented grassland patches in the tropical region using multi-seasonal synthetic aperture radar (SAR) and optical satellite images. *International Journal of Remote Sensing*, 42(10), 3938–3954. <https://doi.org/10.1080/01431161.2021.1881181>
- Banerjee, S., Das, D., Zhang, H., & John, R. (2023). Grassland-woodland transitions over decadal timescales in the Terai-Duar savanna and grasslands of the Indian subcontinent. *Forest Ecology and Management*, 530, 120764. <https://doi.org/10.1016/j.foreco.2022.120764>
- Peet, N. B., Watkinson, A. R., Bell, D. J., & Kattel, B. J. (1999). Plant diversity in the threatened sub-tropical grasslands of Nepal. *Biological Conservation*, 88(2), 193–206. [https://doi.org/10.1016/s0006-3207\(98\)00104-9](https://doi.org/10.1016/s0006-3207(98)00104-9)
- S., S., A., D., S., K. R., & R., P. S. (2016). Plant diversity in terai grassland vegetation: a landscape level assessment with special reference to north-eastern uttar pradesh, India. *International Journal of Biodiversity and Conservation*, 8(12), 365–381. <https://doi.org/10.5897/ijbc2016.0998>
- Pandey, A., Singh, G., Palni, S., Chandra, N., Rawat, J., & Singh, A. P. (2021). Application of remote sensing in alpine grasslands cover mapping of western Himalaya, Uttarakhand, India. *Environmental Monitoring and Assessment*, 193(4). <https://doi.org/10.1007/s10661-021-08956-9>
- Saha, K., Chandran, M., Negi, R., & Guleri, S. (2024). Challenges and Opportunities in Conserving Grassland Ecosystems of Western Himalayan region. *Phytotalks*, 1(2), 131–142. <https://doi.org/10.21276/pt.2024.1.2.7>
- Padbhushan, R., Sharma, S., Rana, D. S., Kumar, U., Kohli, A., & Kumar, R. (2020). Delineate Soil Characteristics and Carbon Pools in Grassland Compared to Native Forestland of India: A Meta-Analysis. *Agronomy*, 10(12), 1969. <https://doi.org/10.3390/agronomy10121969>
- Mehrotra, A., & Jain, S. K. (2024). Endemism in Indian Grasses-Tribe Andropogoneae. *Nelumbo*, 51–58. <https://doi.org/10.20324/nelumbo/v22/1980/75358>

Ashwatha, K. N. (2020). A Geographical Analysis of Challakere Amrit Mahal Kaval Grasslands. Using Remote Sensing and GIS Technologies. *Journal of Geography, Environment and Earth Science International*, 56–71. <https://doi.org/10.9734/jgeesi/2020/v24i730243>

Ballabh, V. (2024). Transitions in Socio-Economic Dimensions of Adivasi Landscape. *INDIAN JOURNAL OF AGRICULTURAL ECONOMICS*. <https://doi.org/10.63040/ijae.vol.79.issue.01.003>.

Joshi, A., Sankaran, M., & Ratnam, J. (2018). 'Foresting' the grassland: Historical management legacies in forest-grassland mosaics in southern India, and lessons for the conservation of tropical grassy biomes. *Biological Conservation*. <https://doi.org/10.1016/j.biocon.2018.05.029>.

Bhasin, M. K., & Nag, S. (2007). Demography of the Tribal Groups of Rajasthan: 1. Population Structure. *The Anthropologist*, 9(1), 1–37. <https://doi.org/10.1080/09720073.2007.11890977>

Shrivastava, Y., & Joshi, P. (2001). Biodiversity in Folk-Beliefs and Practices Among the Tribals of Rajasthan. *Journal of Human Ecology*, 12(2), 141–146. <https://doi.org/10.1080/09709274.2001.11907594>

Rastogi, T., Devi, S. M., & Tomar, M. (2024). Bhil Art A Critical Literature Review on Tradition, Expression, and Cultural Preservation. *Eduphoria-An International Multidisciplinary Magazine*, 02(02), 98–106. <https://doi.org/10.59231/eduphoria/230409>

Chaudhari, M. V. (2022). Tribals living in central Gujarat. *RESEARCH REVIEW International Journal of Multidisciplinary*, 7(12), 06–14. <https://doi.org/10.31305/rrijm.2022.v07.i12.002>

JADHAV, R. N., KIMOTHI, M. M., & KANDYA, A. K. (1993). Grassland mapping/monitoring of Banni, Kachchh (Gujarat) using remotely-sensed data. *International Journal of Remote Sensing*, 14(17), 3093–3103. <https://doi.org/10.1080/01431169308904422>

Paul, S., Saha, S., Nigam, P., Ali, S. Z., Page, N., Khan, A. S., Kumar, M., Habib, B., Mohan, D., Panday, B., & Mondol, S. (2023). Spatiotemporal evaluation of waning grassland habitats for swamp deer conservation across the human-dominated upper Gangetic Plains, India. *Environmental Conservation*, 50(3), 169–178. <https://doi.org/10.1017/s0376892923000140>

Hazarika, A., Nath, A., Reang, D., Pandey, R., Sileshi, G., & Das, A. (2024). Climate change vulnerability and adaptation among farmers practicing shifting agriculture in the Indian Himalayas. *Environmental and Sustainability Indicators*. <https://doi.org/10.1016/j.indic.2024.100430>.

Sharma, C. (2024). Contemporary Development Discourse in Northeast India and its Impact on the Tribal Communities. *Sociological Bulletin*, 73, 467 - 480. <https://doi.org/10.1177/00380229241287396>.

Murali, R., Bijoor, A., Thinley, T., Gurmet, K., Chunit, K., Tobge, R., Thuktan, T., Suryawanshi, K., Nagendra, H., & Mishra, C. (2022). Indigenous governance structures for maintaining an ecosystem service in an agro-pastoral community in the Indian Trans Himalaya. *Ecosystems and People*, 18, 303 - 314. <https://doi.org/10.1080/26395916.2022.2067241>.

Vijayan, D., Kaechele, H., Girindran, R., Chattopadhyay, S., Lukas, M., & Arshad, M. (2021). Tropical forest conversion and its impact on indigenous communities Mapping forest loss and shrinking gathering grounds in the Western Ghats, India. *Land Use Policy*, 102, 105133. <https://doi.org/10.1016/j.landusepol.2020.105133>.

Science of Sustainability



ECOSYSTEMS IN TRANSITION:

CURIOSITY, CONFLICT, AND CONSERVATION

Dr. Aritra Mukherjee, Research Assistant (PFRI)

Introduction

The stability and composition of grassland and wetland ecosystems are increasingly compromised by the convergence of climate variability, shifting disturbance regimes, and anthropogenic pressures. In semi-arid grasslands, these transitions are often characterized by phase shifts and compositional gradients rather than abrupt thresholds, driven primarily by grazing intensity and biotic interactions (Porensky et al., 2016; Jamiyansharav et al., 2018). Similarly, peatland wetlands face significant functional alterations as hydrological shifts dictate their capacity to serve as either carbon sinks or sources (Huang et al., 2021; Koch et al., 2023). Understanding these transitions requires a shift from traditional observation to technological improvisation in impact assessment. While advanced tools such as deep learning and environmental DNA (eDNA) offer unprecedented precision, their deployment introduces socio-technical conflicts regarding data governance, community exclusion, and the ethics of digital surveillance (Sandbrook et al., 2021; Simlai & Sandbrook, 2021). This review synthesizes current literature on the mechanistic drivers of ecosystem transitions and evaluates the efficacy of emerging technologies in conservation and impact assessment.

Mechanistic Drivers and State Transitions in Grasslands

The dynamics of semi-arid grasslands are governed by state-and-transition models

where grazing and climate variability function as primary drivers (Jamiyansharav et al., 2018). Long-term grazing typically induces slow and reversible vegetation changes, though it may not always trigger alternative stable states (Porensky et al., 2016). Biotic interactions, specifically the competition between grasses and shrubs, further modulate these transitions. During early successional stages, grasses can effectively suppress shrub expansion; however, this regulatory capacity diminishes as shrubs mature (Pierce et al., 2018; Pierce et al., 2019). Woody plant encroachment, facilitated by rising CO₂ and fire suppression, has become a global driver of biodiversity loss, with approximately 87% of affected sites experiencing declines in herbaceous species richness (Wieczorkowski & Lehmann, 2022; Ratajczak et al., 2012). Meta-analyses indicate that these losses intensify once woody cover exceeds a threshold of 30% to 50% (Teleki et al., 2020; Silva et al., 2016).



Source: Freepik

Hydrological Controls and Carbon Sequestration in Peatlands

In peatland ecosystems, water table depth functions as the master control for carbon sequestration (Rayment et al., 2021; Koch et al., 2023). Hydrological drawdown accelerates peat decomposition and increases CO₂ emissions, which often overrides any reduction in methane flux (Huang et al., 2021; Liu et al., 2022). Critical thresholds for water table depth are identified at 20 to 30 centimeters; beyond these depths, annual carbon sequestration often approaches zero (Kwon et al., 2022; Zhong et al., 2020). Global projections suggest that continued water table lowering will add approximately 0.7 to 0.9 gigatonnes of CO₂ equivalent per year by 2100 (Huang et al., 2021; Li et al., 2025). While rewetting can restore carbon sink functionality, the recovery process is often influenced by legacy effects from previous drought or drainage cycles (Mander et al., 2023).

Technological Improvisation in Impact Assessment

The integration of deep learning has significantly improved the delineation of complex wetland features and the detection of small-scale degradation (Rezaee et al., 2018; Jamali et al., 2022). Convolutional Neural Networks and U-Net architectures demonstrate accuracies significantly higher than traditional machine learning methods for complex wetland classes (Rezaee et al., 2018). Furthermore, environmental DNA metabarcoding has emerged as a high-sensitivity tool for monitoring vertebrate biodiversity, particularly for rare or cryptic species that are difficult to detect via conventional surveys (Valentini et al., 2016; Fediajevaitė et al., 2021). For micro-topographical assessments, terrestrial LiDAR and high-density UAV platforms can resolve elevation changes at the millimeter to centimeter scale, providing essential data for restoration planning (Gray et al., 2018; Chen et al., 2023; Copeland et al., 2021).

Table 1: Comparative Performance of Improvised Assessment Technologies Socio-Technical Conflict and Governance

Technology	Primary Application	Quantified Performance Gain / Accuracy	Key Citation
Deep Learning (CNN/U-Net)	Wetland class delineation	Superior accuracy over Random Forest/SVM	Rezaee et al. (2018)
eDNA Metabarcoding	Vertebrate biodiversity monitoring	High sensitivity for rare and cryptic species	Valentini et al. (2016)
UAV-LiDAR	Micro-topography change detection	~4 cm median vertical error in grasslands	Gray et al. (2018)
Deep CNN (InSAR)	Hydrological barrier detection	Up to 84% accuracy for roads and dikes	Hübinger et al. (2024)
IoT Sensor Networks	Community-led monitoring	Enhanced real-time data for local management	Soifer et al. (2024)

Socio-Technical Conflict and Governance

The transition toward automated monitoring introduces complex socio-economic trade-offs. Participatory models and smartphone-enabled tools can empower communities and strengthen local management rules (Soifer et al., 2024; Sampaio et al., 2025). However, a digital divide persists, where technical complexity may concentrate power within NGOs or state agencies and exclude marginalized populations (Andrachuk et al., 2019; Shrestha & Lapeyre, 2018). Digital surveillance tools, including drones and camera traps, also carry risks of harm and criminalization if deployed without local consent or transparency (Parris-Piper et al., 2022; Simlai & Sandbrook, 2021). Responsible implementation requires the co-design of monitoring systems with local stakeholders to ensure that technology supports community rights and data sovereignty (Sandbrook et al., 2021; Kowler et al., 2020).

Conclusion

Current evidence underscores that ecosystems in transition are shaped by complex interactions between climate, disturbance, and biotic feedbacks. Precision conservation technologies, ranging from machine learning models to eDNA and IoT networks, provide the necessary tools to detect these shifts before critical thresholds are breached. However, the efficacy of these tools is intrinsically linked to their governance; technology alone cannot resolve the structural drivers of biodiversity loss or carbon stock depletion. The successful conservation of grasslands and wetlands in a warming world will depend on the integration of data-rich monitoring with ethical, community-led management frameworks. Future research should focus on head-to-head trials of precision versus traditional restoration frameworks to quantify the direct impact of technological improvisation on long-term ecological outcomes.



References

- Andrachuk, M., Marschke, M., Hings, C., & Armitage, D. (2019). Smartphone technologies supporting community-based environmental monitoring and implementation: a systematic scoping review. *Biological Conservation*, 237, 233-242. <https://doi.org/10.1016/j.biocon.2019.07.026>
- Chen, Z., Zhang, T., Jiao, C., Zhang, W., Han, L., Fu, Z., Sun, Z., Liu, Z., Wen, Z., & Yu, G. (2023). Using the dynamics of productivity and precipitation-use efficiency to detect state transitions in Eurasian grasslands. *Frontiers in Ecology and Evolution*, 11, 1189059. <https://doi.org/10.3389/fevo.2023.1189059>
- Copeland, S. M., Baughman, O. W., Boyd, C. S., Davies, K. W., Kerby, J., Kildisheva, O. A., & Svejcar, T. (2021). Improving restoration success through a precision restoration framework. *Restoration Ecology*, 29(2), e13348. <https://doi.org/10.1111/rec.13348>
- Fediajevaitė, J., Priestley, V., Arnold, R., & Savolainen, V. (2021). Meta-analysis shows that environmental DNA metabarcoding improves monitoring of freshwater biodiversity. *Communications Biology*, 4(1), 1-11. <https://doi.org/10.1038/s42003-021-02803-2>
- Gray, P. C., Ridge, J. T., Poulin, S. K., Johnston, D. W., Rodriguez, A. B., & Fodrie, F. J. (2018). Sentinel-2 Data Consumption for Wetland Monitoring in a Coastal Plain Estuary. *Remote Sensing*, 10(6), 849. <https://doi.org/10.3390/rs10060849>
- Hu, Z., Guo, Q., Li, S., Piao, S., Knapp, A., Ciais, P., Li, X., & Yu, G. (2018). Shifts in the dynamics of productivity signal ecosystem state transitions at the biome-scale. *Ecology Letters*, 21(10), 1457-1466. <https://doi.org/10.1111/ele.13126>
- Huang, Y., Ciais, P., Luo, Y., Zhu, D., Wang, Y., Qiu, C., Goll, D., Guenet, B., Makowski, D., De Graaf, I., Leifeld, J., Kwon, M., Hu, J., & Qu, L. (2021). Tradeoff of CO₂ and CH₄ emissions from global peatlands under water-table drawdown. *Nature Climate Change*, 11(7), 618-622. <https://doi.org/10.1038/s41558-021-01059-w>
- Hübinger, C., Fluet-Chouinard, E., Hugelius, G., Peña, F., & Jaramillo, F. (2024). Automating the detection of hydrological barriers and fragmentation in wetlands using deep learning and InSAR. *Remote Sensing of Environment*, 314, 114314. <https://doi.org/10.1016/j.rse.2024.114314>
- Jamali, A., Mahdianpari, M., Brisco, B., Mao, D., Salehi, B., & Mohammadimanesh, F. (2022). 3DUNetGSFormer: A deep learning pipeline for complex wetland mapping using generative adversarial networks and Swin transformer. *Ecological Informatics*, 72, 101904. <https://doi.org/10.1016/j.ecoinf.2022.101904>
- Jamiyansharav, K., Fernández-Giménez, M., Angerer, J., Yadamsuren, B., & Dash, Z. (2018). Plant community change in three Mongolian steppe ecosystems 1994-2013: applications to state-and-transition models. *Ecosphere*, 9(6), e02145. <https://doi.org/10.1002/ecs2.2145>
- Koch, J., Elsgaard, L., Greve, M., Gyldenkerne, S., Hermansen, C., Levin, G., Wu, S., & Stisen, S. (2023). Water-table-driven greenhouse gas emission estimates guide peatland restoration at national scale. *Biogeosciences*, 20(12), 2387-2403. <https://doi.org/10.5194/bg-20-2387-2023>
- Kowler, L., Pratihast, A., Del Arco, A., Larson, A., Braun, C., & Herold, M. (2020). Aiming for Sustainability and Scalability: Community Engagement in Forest Payment Schemes. *Forests*, 11(4), 444. <https://doi.org/10.3390/f11040444>
- Kwon, M., Ballantyne, A., Ciais, P., Qiu, C., Salmon, E., Raoult, N., Guenet, B., Göckede, M., Euskirchen, E., Nykänen, H., Schuur, E., Turetsky, M., Dieleman, C., Kane, E., & Zona, D. (2022). Lowering water table reduces carbon sink strength and carbon stocks in northern peatlands. *Global Change Biology*, 28(22), 6752-6770. <https://doi.org/10.1111/gcb.16394>

- Li, J., Yuan, J., Ciais, P., Kang, H., Freeman, C., Huang, Y., Dong, Y., Liu, D., Li, Y., & Ding, W. (2025). Two decades of improved wetland carbon sequestration in northern mid-to-high latitudes are offset by tropical and southern declines. *Nature Ecology & Evolution*, 9(2), 1861-1872. <https://doi.org/10.1038/s41559-025-02809-1>
- Liu, H., Gu, Y., Ge, J., Yu, Z., Xu, X., Zhang, Z., Cheng, S., & Xie, S. (2022). The response of the Dajiuhu Peatland ecosystem to hydrological variations: Implications for carbon sequestration and peatlands conservation. *Journal of Hydrology*, 613, 128307. <https://doi.org/10.1016/j.jhydrol.2022.128307>
- Mander, Ü., Espenberg, M., Melling, L., & Kull, A. (2023). Peatland restoration pathways to mitigate greenhouse gas emissions and retain peat carbon. *Biogeochemistry*, 167(2-3), 523-543. <https://doi.org/10.1007/s10533-023-01103-1>
- Parris-Piper, N., Dressler, W., Satizábal, P., & Fletcher, R. (2022). Automating violence? The anti-politics of 'smart technology' in biodiversity conservation. *Biological Conservation*, 276, 109859. <https://doi.org/10.1016/j.biocon.2022.109859>
- Pierce, N., Archer, S., & Bestelmeyer, B. (2019). Competition suppresses shrubs during early, but not late, stages of arid grassland–shrubland state transition. *Functional Ecology*, 33(10), 2007-2017. <https://doi.org/10.1111/1365-2435.13336>
- Pierce, N., Archer, S., Bestelmeyer, B., & James, D. (2018). Grass-Shrub Competition in Arid Lands: An Overlooked Driver in Grassland–Shrubland State Transition? *Ecosystems*, 22(3), 619-628. <https://doi.org/10.1007/s10021-018-0290-9>
- Porensky, L., Mueller, K., Augustine, D., & Derner, J. (2016). Thresholds and gradients in a semi-arid grassland: long-term grazing treatments induce slow, continuous and reversible vegetation change. *Journal of Applied Ecology*, 53(4), 1013-1022. <https://doi.org/10.1111/1365-2664.12630>
- Ratajczak, Z., Nippert, J., & Collins, S. (2012). Woody encroachment decreases diversity across North American grasslands and savannas. *Ecology*, 93(4), 697-703. <https://doi.org/10.1890/11-1199.1>
- Rayment, E., Ridley, M., Stanley, L., Williamson, K., Worrall, F., Morrison, R., ... & Evans, C. (2021). Overriding water table control on managed peatland greenhouse gas emissions. *Nature*, 593(7860), 548-552. <https://doi.org/10.1038/s41586-021-03523-1>
- Rezaee, M., Mahdianpari, M., Salehi, B., Brisco, B., & Mohammadimanesh, F. (2018). Deep Convolutional Neural Networks for Complex Wetland Classification Using Optical Remote Sensing Imagery. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, 11(9), 3030-3039. <https://doi.org/10.1109/JSTARS.2018.2846178>
- Sampaio, R., Morato, R., Nunes, A., & Chiarello, A. (2025). Using camera traps to enhance community-based management of subsistence hunting in the Amazon. *Conservation Biology*, 39(1), e70044. <https://doi.org/10.1111/cobi.70044>
- Sandbrook, C., Clark, D., Toivonen, T., Simlai, T., O'Donnell, S., Cobbe, J., & Adams, W. (2021). Principles for the socially responsible use of conservation monitoring technology and data. *Conservation Science and Practice*, 3(5), e374. <https://doi.org/10.1111/csp2.374>
- Shrestha, Y., & Lapeyre, R. (2018). Modern Wildlife Monitoring Technologies: Conservationists versus Communities? A Case Study: The Terai-Arc Landscape, Nepal. *Conservation and Society*, 16(1), 91-101. https://doi.org/10.4103/cs.cs_16_83
- Silva, F., Arieira, J., Parolin, P., Cunha, C., & Junk, W. (2016). Shrub encroachment influences herbaceous communities in flooded grasslands of a neotropical savanna wetland. *Applied Vegetation Science*, 19(3), 391-400. <https://doi.org/10.1111/avsc.12230>

- Simlai, T., & Sandbrook, C. (2021). Digital surveillance technologies in conservation and their social implications. In *Conservation Technology* (pp. 201-218). Oxford University Press.
<https://doi.org/10.1093/oso/9780198850243.003.0012>
- Soifer, L., Klings, D., Randriamiharisoa, L., & Scheffers, B. (2024). Decision analysis shows scientific and economic value of community-based monitoring in Madagascar. *bioRxiv*.
<https://doi.org/10.1101/2024.10.06.616891>
- Teleki, B., Sonkoly, J., Erdős, L., Tóthmérész, B., Prommer, M., & Török, P. (2020). High resistance of plant biodiversity to moderate native woody encroachment in loess steppe grassland fragments. *Applied Vegetation Science*, 23(2), 166-175. <https://doi.org/10.1111/avsc.12474>
- Valentini, A., Taberlet, P., Miaud, C., Civade, R., Herder, J., Thomsen, P. F., ... & Dejean, T. (2016). Next-generation monitoring of aquatic biodiversity using environmental DNA metabarcoding. *Molecular Ecology*, 25(4), 929-942. <https://doi.org/10.1111/mec.13428>
- White, J., Stevens, N., Fisher, J., & Reynolds, C. (2024). Woody plant encroachment drives population declines in 20% of common open ecosystem bird species. *Global Change Biology*, 30(6), e17340.
<https://doi.org/10.1111/gcb.17340>
- Wieczorkowski, J., & Lehmann, C. (2022). Encroachment diminishes herbaceous plant diversity in grassy ecosystems worldwide. *Global Change Biology*, 28(18), 5532-5546.
<https://doi.org/10.1111/gcb.16300>
- Wilcox, B., Birt, A., Fuhlendorf, S., & Archer, S. (2018). Emerging frameworks for understanding and mitigating woody plant encroachment in grassy biomes. *Current Opinion in Environmental Sustainability*, 32, 1-7. <https://doi.org/10.1016/j.cosust.2018.04.005>
- Zhang, T., Chen, Z., Jiao, C., Zhang, W., Han, L., Fu, Z., Sun, Z., Liu, Z., Wen, Z., & Yu, G. (2023). Using the dynamics of productivity and precipitation-use efficiency to detect state transitions in Eurasian grasslands. *Frontiers in Ecology and Evolution*, 11, 1189059.
<https://doi.org/10.3389/fevo.2023.1189059>
- Zhong, Y., Jiang, M., & Middleton, B. (2020). Effects of water level alteration on carbon cycling in peatlands. *Ecosystem Health and Sustainability*, 6(1), 1806113.
<https://doi.org/10.1080/20964129.2020.1806113>



Source: Communication Department, PERI

ECOSYSTEM SERVICES OF THE EAST KOLKATA WETLANDS:

VALUATION, SOCIO-ECOLOGICAL SIGNIFICANCE, AND POLICY IMPLICATIONS FOR SUSTAINABLE URBAN WETLAND MANAGEMENT

Dr. Bhaskar Deb Bhattacharya, Senior Research Officer (PFRI)

Abstract

Wetlands are among the most productive ecosystems on Earth, providing a wide range of ecosystem services that sustain ecological balance, support livelihoods, and contribute significantly to economic development. Among the world's urban wetlands, the East Kolkata Wetlands (EKW) represent a globally recognized example of nature-based resource recovery and sustainable waste management. This review paper explores the concept of ecosystem service valuation through a global theoretical perspective before narrowing its focus to the socio-ecological and economic significance of the East Kolkata Wetlands. The study synthesizes existing literature on direct and indirect ecosystem services provided by EKW, including wastewater treatment, aquaculture-based food production, carbon sequestration, biodiversity conservation, and livelihood support.

The review evaluates valuation approaches such as Contingent Valuation Method, Travel Cost Method, and ecosystem-based accounting frameworks to estimate both market and non-market values of wetland services. Furthermore, the paper examines emerging opportunities such as carbon trading and ecotourism development as innovative pathways for sustainable financing and conservation.

Policy frameworks, governance challenges, and stakeholder perceptions are analyzed to identify gaps between valuation outcomes and implementation strategies. Spatial degradation patterns and socio-economic perceptions are also discussed to highlight the urgency of integrating ecosystem service valuation into regional planning. The review concludes by proposing integrated policy and management strategies aimed at strengthening conservation, improving community participation, and ensuring long-term ecological and economic sustainability of the East Kolkata Wetlands.

Keywords: Ecosystem services, Wetland valuation, Urban wetlands, East Kolkata Wetlands, Wastewater recycling, Carbon sequestration, Ecotourism, Sustainable livelihoods



Source: Communication Department, PFRI

Introduction

Wetlands are widely recognized as vital ecological systems that provide numerous ecosystem services essential for environmental sustainability and human well-being. Globally, wetlands contribute significantly to climate regulation, water purification, biodiversity conservation, and socio-economic development. However, increasing urbanization, industrialization, and land-use change have led to widespread wetland degradation, posing serious threats to ecosystem resilience and human livelihoods.

The concept of ecosystem services emerged as a framework to recognize the benefits humans derive from natural ecosystems. Ecosystem services are broadly categorized into provisioning, regulating, cultural, and supporting services. Economic valuation of these services has gained increasing attention worldwide as policymakers seek to integrate ecological benefits into development planning and resource management strategies. Several valuation frameworks have been developed to quantify ecosystem contributions, including market-based valuation, non-market valuation methods, and integrated environmental-economic accounting systems.

Urban wetlands represent particularly important ecological assets due to their multifunctional roles in managing waste, reducing urban flooding, and supporting biodiversity. The East Kolkata Wetlands (EKW) constitute one of the largest wastewater-fed aquaculture systems in the world and serve as a unique model of ecological engineering. Recognized as a Ramsar Site of international importance,

the East Kolkata Wetlands cover approximately 12,500 hectares and provide livelihood support to thousands of local residents. This review aims to provide a comprehensive synthesis of ecosystem services provided by the East Kolkata Wetlands and evaluate their economic and socio-ecological significance. The paper integrates global theoretical frameworks with region-specific analysis to highlight the potential of ecosystem service valuation in strengthening conservation and sustainable management practices.

Conceptual Framework of Ecosystem Services Valuation

Global Perspectives on Ecosystem Service Valuation

Ecosystem service valuation has evolved significantly over the past decades, driven by the need to quantify ecological contributions in economic terms. The Millennium Ecosystem Assessment (MEA) introduced a widely accepted classification of ecosystem services into provisioning, regulating, cultural, and supporting services. Later frameworks, such as the Economics of Ecosystems and Biodiversity (TEEB) initiative, further emphasized integrating ecological valuation into policy decisions. Various methodologies are employed to quantify ecosystem services, including Market-based valuation, replacement cost method, avoided cost method, Contingent Valuation Method (CVM), Travel Cost Method (TCM), benefit transfer approaches, and integrated ecosystem accounting. These methods help capture both tangible and intangible values associated with natural ecosystems.

Economic Importance of Wetland Ecosystem Services

Wetlands provide critical ecosystem functions that translate into measurable economic benefits. These include – Natural wastewater treatment, flood control, carbon sequestration, fisheries and agriculture, tourism and recreation. Globally, wetland ecosystem services are estimated to contribute billions of dollars annually to national economies. However, many services remain undervalued due to their non-market nature.

Overview of the East Kolkata Wetlands

Geographic and Ecological Characteristics

The East Kolkata Wetlands are located on the eastern fringes of Kolkata city and form a complex network of natural and man-made wetlands, including fish ponds (locally known as bheries), agricultural lands, and marshes. These wetlands serve as a natural treatment system for municipal wastewater generated by Kolkata. Key ecological features include – wastewater-fed aquaculture systems, extensive marshlands, high biodiversity, seasonal water bodies, and integrated farming systems.

Socio-Economic Significance

The East Kolkata Wetlands support livelihoods for thousands of people through aquaculture, agriculture, waste recycling, and fish production. The wetlands also contribute significantly to food security and urban sustainability.

Ecosystem Services Provided by the East Kolkata Wetlands

Provisioning Services

The East Kolkata Wetlands (EKW) form one of the world's largest wastewater-based resource recovery systems,

The East Kolkata Wetlands (EKW) form one of the world's largest wastewater-based resource recovery systems, where sewage is transformed into food and materials. This peri-urban landscape sustains fisheries, agriculture, and multiple raw-material-based livelihoods central to Kolkata's food security and local economies (Chakraborty et al., 2019; Dey & Banerjee 2013). Provisioning services in EKW arise from wastewater-fed aquaculture, sewage- and garbage-based farming, and associated biomass uses, tightly integrating waste treatment with production.

Fish Production

Wastewater-fed aquaculture is the flagship provisioning service of EKW. Around 254-272 sewage-fed ponds (bheries) over ~4,000 ha use city sewage to produce fish, treating up to hundreds of millions of litres of wastewater daily (Kumar et al., 2023). Annual fish production is reported around 10,000-13,000 tonnes, with average yields near 5 t/ha, supplying cheap protein to Kolkata and supporting tens of thousands of livelihoods in fisheries and associated work (Dey & Banerjee 2013). Multiple carp and tilapia species dominate production, feeding both local and urban markets (Basu et al., 2023).

Agricultural Production

EKW integrates pond effluent-based paddy cultivation and garbage- or sewage-based vegetable farming with aquaculture, making production processes mutually complementary. Recycled wastewater and organic wastes support vegetables (e.g., spinach, eggplant, tomato, pumpkin, cabbage), fruits, flowers, and paddy, contributing substantially to Kolkata's daily food supply (Everard et al., 2019).

and organic wastes support vegetables (e.g., spinach, eggplant, tomato, pumpkin, cabbage), fruits, flowers, and paddy, contributing substantially to Kolkata's daily food supply (Everard et al., 2019). Estimated outputs include ~16,000 tonnes of paddy per year and ~156 tonnes of vegetables per day. Reclaimed agricultural lands also maintain high soil fertility driven by nutrient-rich inputs and active microbial communities (Ghosh et al., 2024).

Raw Materials

Wetland users depend on EKW for a range of material goods. Stakeholders report collecting fodder for livestock, firewood/fuelwood, timber wood, and medicinal plants, alongside diverse aquatic biomass. Clay harvested from pond beds is used locally for rebuilding pond banks, and vegetated strips provide plant biomass and other raw materials that support construction and household energy needs.

Regulating Services

The East Kolkata Wetlands provide several regulating ecosystem services that keep Kolkata's environment habitable: wastewater purification, flood mitigation, and climate regulation through carbon storage. Rapid urban expansion, however, is eroding these benefits and increasing the city's environmental risk

Wastewater Treatment

EKW functions as a large, nature-based sewage treatment plant, receiving roughly three-quarters of Kolkata's sewage through canal networks.

- Biological processes – Shallow oxidation ponds use algae–bacteria symbiosis, diverse microbial populations, and solar radiation to remove suspended solids, organic pollutants, nutrients, pathogens, and heavy metals (Bhattacharyya et al., 2025).

- Treatment performance – Measured removal includes about 59% BOD, 80% ammoniacal nitrogen, 90% phosphate, and 99% fecal coliform reduction, with treated water generally meeting inland discharge standards (Khan et al., 2024).
- Coupled reuse – Nutrient-rich effluent supports sewage-fed fisheries, paddy, and vegetable cultivation, turning waste into food and income.

Flood Control

EKW acts as a retardation/absorber basin, storing sewage water and excess rainwater runoff from Kolkata, thus helping manage flooding in neighboring urban areas (Chatterjee et al., 2024). Studies warn that wetland shrinkage and conversion to built-up areas increase flood exposure and disaster risk, as the city loses this natural buffer.

Carbon Sequestration

EKW contributes to climate regulation in two ways –

- Soil and system-level carbon – Constant water saturation slows decomposition, allowing Soil Organic Carbon (SOC) stocks that act as a significant carbon sink and help curb greenhouse gas emissions (Yadav et al., 2024).
- Vegetation and horticulture – Horticultural plants in the wetlands (e.g., ixora, marigold, basil) store substantial carbon in biomass and soils, with some species reaching ~40 t C ha⁻¹ in plant biomass and >50 t C ha⁻¹ SOC, showing strong local carbon sequestration potential (Adhikari et al., 2021).

- Degradation and land-use change threaten these carbon stores and could release stored carbon back to the atmosphere.

Supporting Services

Supporting services in the East Kolkata Wetlands (EKW) are the ecological processes that underpin provisioning and regulating functions, including wastewater treatment, fisheries, and agriculture. These processes include nutrient and carbon cycling, and the maintenance of diverse habitats for aquatic and terrestrial biota

Nutrient Cycling

Wetlands in EKW act as biogeochemical reactors where microbial communities and plankton transform sewage-borne nutrients into biomass, sustaining high productivity and purifying water (Saha et al., 2016).

- Diverse bacterial communities, including sulphate- and nitrate-reducing bacteria, remove sulphate, prevent nitrate-mediated eutrophication, and immobilise metals, thereby supporting nutrient recycling and water quality (Saha et al., 2016).
- Plankton communities (phytoplankton and zooplankton) drive carbon cycling, converting dissolved CO₂ and organic carbon into biomass; conceptual models of carbon flow show their central role in sustaining fish production in sewage-fed ponds (Saha et al., 2016).
- Reclaimed agricultural soils within EKW show high nitrogen, phosphate, and potassium levels, linked to a diverse microbiome (e.g., *Bacillus* spp.), indicating strong soil fertility maintenance through microbial processes (Ghosh et al., 2024).

- Photosynthesis in aquatic plants and microbes further supports nutrient uptake and food-web structure (Mohan et al., 2019).

Habitat Provision

EKW forms a mosaic of ponds, canals, and vegetated areas that provides habitat for a wide range of taxa and supports regional biodiversity –



Source: Communication Department, PFRI

Table 1: Key biotic groups and habitat role in EKW

Biotic group	Habitat role in EKW	Citations
Fish species	39–71 species recorded; supports food and ornamental fish, many threatened; habitat loss and pollution are now major pressures	Mohan et al., 2020
Birds	Bird richness declined from 248 species (1960s) to 72 (2005), reflecting fragmentation and degradation of feeding and roosting sites	Mundoli et al., 2023
Amphibians	Not quantified in these texts, but EKW is recognised as a critical wildlife habitat within Kolkata’s blue landscape	Das, 2025
Aquatic flora	51 aquatic macrophyte species across 27 families were documented, forming a structural habitat and a primary production base	Mandal, & Palit, 2025

Cultural Services

Cultural ecosystem services of the East Kolkata Wetlands (EKW) support recreation, identity, learning, and well-being, alongside their better-known provisioning and regulating roles. These non-material benefits are especially visible in community-managed areas, where people emphasize enjoyment of place, social bonding, and cultural practices linked to the wetland landscape.

Ecotourism

EKW has considerable potential for ecotourism based on its biodiversity and landscape heterogeneity. Surveys show high avian diversity (94 bird species) with extensive areas of high-diversity habitat, indicating strong scope for bird-watching-based nature tourism if priority conservation areas and emergent vegetation along dikes and banks are protected. Butterflies are also diverse (74 species),

underscoring the wetlands’ appeal for broader wildlife observation and nature photography.

More broadly, wetland cultural services in and around Kolkata include recreation, nature enjoyment, and opportunities to ‘simply be there and enjoy the place’, which are highly valued by both community and private users. Experience from urban wetland ‘Nature Parks’ near Kolkata shows visitors are willing to pay for access to secure, green, and recreational wetland spaces, highlighting the feasibility of carefully planned, low-impact nature-based tourism linked to biodiversity conservation

Educational Value

EKW functions as a living laboratory for environmental learning, from school to postgraduate levels.

Arts-based climate and sustainability education projects with local students use the wetlands as context to link climate change, ecology, and livelihoods, emphasizing hands-on activities and community-oriented learning in this ecologically fragile area.

Stakeholder-based ecosystem service assessments and biodiversity surveys (birds, butterflies, microbes, resource-recovery systems) demonstrate that EKW is a key field site for research in wetland ecology, urban sustainability, wastewater reuse, and conservation planning, reinforcing its role as a long-term outdoor classroom for researchers and students.

Economic Valuation of Ecosystem Services in the East Kolkata Wetlands

The East Kolkata Wetlands (EKW) generate substantial economic value by turning wastewater into food, employment, and environmental regulation. Studies highlight both direct market benefits (fish, crops, low-cost treatment) and indirect benefits (flood mitigation, water security, carbon storage), many of which remain undervalued or only partially quantified.

Direct Economic Benefits

- **Fish production revenue** – Sewage-fed aquaculture in EKW supports thousands of families and supplies low-cost fish to Kolkata, forming a critical part of urban food markets and local livelihoods (Dey & Banerjee, 2017). Economic assessments show that, once pollution-control and employment benefits are included, these fisheries become an ‘invaluable and irreplaceable resource,’ even if they may appear marginal as a private business alone.

The opportunity-cost study warns that loss of fisheries and waste-recycling practices would impose high economic costs on the city.

- **Agricultural output** – Wastewater and sludge reuse support paddy and vegetable farming, contributing significantly to food supply, jobs, and ecosystem service value (ESV) for Kolkata (Mukherjee et al., 2021). Agricultural lands in EKW provide food plus regulating services such as soil and water quality regulation and carbon sequestration, with their loss directly reducing ESV and job and food security.
- **Wastewater recycling cost savings** – EKW treats over 70-80% of Kolkata’s sewage through natural, low-energy processes, effectively substituting for costly conventional treatment plants (Mukherjee et al., 2021). This “subsidized service” saves the city construction and operating costs for wastewater infrastructure, while simultaneously generating fish and crops. These services significantly reduce municipal treatment costs.

Indirect Economic Benefits

- **Reduced flood damage** – EKW functions as a retention basin, absorbing sewage and stormwater and reducing flood risk for Kolkata (Chatterjee et al., 2025). Urban encroachment and wetland loss are projected to increase exposure to severe flooding, implying large avoided-damage benefits from conserving wetland storage capacity, even though these are not yet fully monetized.
- **Improved water quality** – By naturally purifying municipal wastewater and supporting groundwater and surface-water quality,

Table 2: Key categories of direct economic benefits in EKW.

Direct benefit type	Main economic contribution	Citations
Sewage-fed fisheries	Low-cost fish, jobs, external pollution benefits	Dey & Banerjee, 2013
Wastewater-based agriculture	Food, employment, added regulating services	Mukherjee et al., 2021
Natural wastewater treatment	Avoided capital/operating costs of plants	Kumar 2018

EKW underpins urban water security. Ecosystem service valuation for Kolkata and EKW estimates total ESV of US\$53-67 million, with more than 50% of this value arising from peri-urban wetlands, largely via water-related services (Mukherjee et al., 2021). Many of these benefits (sewage purification, nutrient retention, biodiversity support) accrue at city or regional scales and are often overlooked in conventional accounts.

- **Carbon storage** – EKW’s soils and sediments act as a significant carbon sink. Carbon budget and sediment studies estimate carbon burial rates of roughly 1.2-2.5 t C ha⁻¹ yr⁻¹, equivalent (when up-scaled) to about 57–114 Gg CO₂ captured annually for the full wetland area. A recent study further estimated the social cost of carbon benefit from EKW’s carbon storage at about US\$184.71 ha⁻¹ yr⁻¹ (Sen et al., 2024). These climate-regulating services are typically absent from local economic decision-making despite clear monetary value.

Reviews and ecosystem service assessments stress that many indirect benefits-flood buffering, water regulation, biodiversity support, and

climate regulation are under-represented and under-valued in existing literature and policy, particularly for peri-urban wetlands like EKW. Difficulties in attributing benefits across scales (local to global), limited data, and complex ecological interactions all contribute to this undervaluation.

Non-Market Valuation Methods

The assessment of ecosystem services in the East Kolkata Wetlands requires the application of non-market valuation techniques, as many of its benefits-such as nutrient recycling, biodiversity support, and livelihood provisioning-are not traded in conventional markets. These methods help capture the socio-economic importance of the wetlands beyond direct financial returns.

Contingent Valuation Method (CVM)

The Contingent Valuation Method (CVM) is a stated preference approach that estimates stakeholders’ willingness-to-pay (WTP) for the conservation and sustainable management of ecosystem services. In the context of EKW, CVM can be employed to

assess how local communities, urban residents, and policymakers value services such as wastewater treatment, flood regulation, and habitat conservation. Given the dependence of peri-urban populations on wetland-based livelihoods, CVM also enables the inclusion of non-use values, such as existence and bequest values, thereby providing a comprehensive estimate of the wetlands' societal importance.

Travel Cost Method (TCM)

The Travel Cost Method (TCM) is a revealed preference technique used to evaluate the recreational and cultural value of ecosystems by analyzing the expenditures incurred by visitors.

Although EKW is not a conventional tourism hotspot, it holds increasing potential for eco-tourism, research visits, and educational exposure. TCM can capture the implicit value visitors place on these experiences by considering travel expenses, time costs, and frequency of visits. This approach is particularly relevant for understanding the emerging cultural ecosystem services of EKW, especially in the context of urban environmental awareness and nature-based learning.

Benefit Transfer Method

The Benefit Transfer Method involves applying valuation estimates derived from similar wetland ecosystems to the study area, with necessary adjustments for ecological, socio-economic, and geographic differences. For EKW, this approach is useful where primary data collection is constrained by time or resources.

By drawing on valuation studies from comparable Ramsar sites or urban wetlands, this method provides a cost-effective means to approximate the economic value of ecosystem services such as water purification, carbon sequestration, and fisheries support. However, careful calibration is essential to ensure contextual relevance and to minimize transfer errors.

Carbon Trading and Climate Finance Opportunities

Wetland ecosystems such as the East Kolkata Wetlands function as significant carbon sinks, positioning them as viable candidates for emerging climate finance mechanisms. Their capacity for long-term carbon sequestration in biomass and sediment systems creates opportunities to access carbon credit markets through structured interventions such as afforestation-based carbon sequestration projects, wetland restoration, and improved wastewater-fed aquaculture systems that enhance carbon retention. In addition, the scope for developing blue carbon initiatives—though traditionally associated with coastal ecosystems—can be contextually adapted to EKW's unique ecological processes, particularly in relation to organic matter cycling and sediment carbon storage. Participation in broader climate mitigation programs, including voluntary carbon markets and nationally aligned offset schemes, can further enable revenue generation while incentivizing conservation. The strategic integration of carbon trading frameworks with wetland management not only provides financial sustainability but also strengthens long-term ecological resilience, aligning local livelihood systems with global climate goals.

Ecotourism Potential and Livelihood Diversification

Ecotourism presents a viable pathway for aligning conservation goals with livelihood enhancement in the East Kolkata Wetlands, given its rich biodiversity and proximity to a major urban center. The wetland landscape supports a range of low-impact, nature-based activities such as bird watching, particularly during migratory seasons, as well as guided nature trails that showcase its unique wastewater-fed ecological processes.

The establishment of wetland interpretation centers can further facilitate environmental education, research engagement, and awareness-building among visitors. Additionally, community-based tourism models—where local fishers, farmers, and youth actively participate as guides, service providers, and knowledge holders—can ensure equitable benefit-sharing while preserving traditional ecological knowledge. Collectively, these ecotourism interventions can diversify income sources for local communities, reduce pressure on primary resource extraction, and strengthen incentives for long-term conservation of the wetland ecosystem.

Spatial Analysis of Wetland Degradation

Spatial analysis provides a robust framework for quantifying temporal and spatial changes in the extent, structure, and ecological integrity of wetlands such as the East Kolkata Wetlands. Using geospatial tools, including remote sensing and Geographic Information Systems (GIS), multi-temporal satellite imagery (e.g., Landsat, Sentinel) can be analyzed to detect

land-use and land-cover (LULC) transitions, particularly the conversion of wetland areas into built-up land, agriculture, or aquaculture intensification zones. Land-use change serves as a primary indicator of anthropogenic pressure, often leading to habitat alteration and hydrological disruption.

Vegetation loss can be assessed through spectral indices such as the Normalized Difference Vegetation Index (NDVI), which enables the monitoring of changes in wetland macrophytes and surrounding green cover, reflecting ecosystem health and productivity. Similarly, water quality decline can be inferred using indices like the Normalized Difference Water Index (NDWI), turbidity measures, and chlorophyll concentration proxies derived from satellite data, supplemented by in situ observations of parameters such as dissolved oxygen, biochemical oxygen demand, and nutrient loads. To further understand structural degradation, landscape metrics derived from spatial analysis—such as patch size, edge density, fragmentation index, and connectivity measures—are applied to quantify the degree of wetland fragmentation and habitat discontinuity.

Metrics generated using tools like FRAGSTATS or similar spatial modelling platforms provide insights into the spatial configuration of wetland patches and their ecological implications, including reduced biodiversity support and impaired ecosystem service delivery. Such integrative spatial assessments are essential for identifying degradation hotspots, informing restoration prioritization, and supporting evidence-based wetland management strategies.

Policy Frameworks and Governance Challenges

Existing Policy Frameworks

- Wetland conservation in the East Kolkata Wetlands is guided by a multi-layered institutional and legal framework integrating international, national, and state-level instruments.
- At the international level, the Ramsar Convention provides the overarching principle of ‘wise use,’ promoting sustainable management while maintaining ecological character; EKW has been designated as a Ramsar Site since 2002.
- At the national level, the Wetlands (Conservation and Management) Rules, 2017, notified by the Ministry of Environment, Forest and Climate Change, establish regulatory mechanisms for wetland identification, notification, monitoring, and protection, emphasizing ecosystem services such as water purification, flood control, and biodiversity conservation.
- At the state level, the East Kolkata Wetlands (Conservation and Management) Act, 2006, and associated Rules (2006) provide a site-specific legal framework, leading to the establishment of the East Kolkata Wetlands Management Authority (EKWMA) responsible for boundary demarcation, land-use regulation, pollution control, and biodiversity conservation.
- Additional policy support is derived from broader frameworks such as the National Environment Policy (2006), integrating wetland conservation into sustainable development planning.

Policy-Practice Gaps

- Despite a comprehensive policy architecture, significant gaps persist between policy formulation and on-ground implementation in EKW.
- Weak enforcement remains a critical issue, with regulatory violations often going unchecked due to limited institutional capacity, inadequate monitoring infrastructure, and governance inefficiencies.
- Encroachment and land-use conversion driven by rapid urban expansion in Kolkata’s peri-urban fringe have resulted in substantial wetland loss and fragmentation, undermining ecological functions such as wastewater treatment and flood buffering.
- Pollution from urban sewage, industrial discharge, and solid waste mismanagement further degrades water quality and ecosystem health, threatening the sustainability of traditional wastewater-fed aquaculture systems.
- Institutional fragmentation, involving multiple agencies (e.g., EKWMA, municipal bodies, panchayats), leads to overlapping jurisdictions, poor coordination, and regulatory inconsistencies, weakening governance effectiveness.
- Limited stakeholder participation and insufficient integration of local community knowledge into decision-making processes further widen the policy–practice divide.

Integration of Valuation into Policy

- Incorporating ecosystem service valuation into policy and planning frameworks is increasingly recognized as essential for improving wetland governance and resource allocation.
- Economic valuation of services such as wastewater treatment, fisheries production, carbon sequestration, and flood regulation can make the ‘invisible benefits’ of wetlands explicit, thereby strengthening the case for conservation in policy discourse.
- Integrating valuation into cost–benefit analyses, land-use planning, and urban development strategies can help balance competing demands between ecological preservation and economic growth.
- Valuation-informed policy instruments—such as payment for ecosystem services (PES), green accounting, and climate finance mechanisms—can incentivize sustainable practices and enhance long-term ecological resilience.
- For EKW, embedding ecosystem valuation within governance frameworks can facilitate evidence-based decision-making, improve inter-sectoral coordination, and align local conservation priorities with national and global sustainability goals.

Discussion

The synthesis of available literature highlights that the East Kolkata Wetlands represent a globally unique model of nature-based urban metabolism, where ecological processes are directly linked with economic production and livelihood systems. Unlike conventional engineered infrastructure, EKW demonstrates how wastewater can be efficiently recycled through low-energy,

biologically driven pathways to generate provisioning services such as fish and agricultural produce, while simultaneously delivering regulating services including water purification, flood buffering, and carbon sequestration. This multifunctionality underscores the wetland’s high socio-ecological value, which extends beyond local benefits to city-scale environmental sustainability. However, the review also reveals a persistent undervaluation of ecosystem services, particularly indirect and non-market benefits such as climate regulation, biodiversity support, and cultural services. While valuation approaches, including market-based assessments, Contingent Valuation Method (CVM), and benefit transfer techniques, provide useful estimates, significant methodological gaps remain in capturing the full spectrum of ecosystem contributions, especially across spatial and temporal scales. This underestimation often results in policy decisions that favor short-term economic gains, such as land conversion, over long-term ecological sustainability.

The analysis further indicates that despite a relatively strong policy framework, including Ramsar recognition and dedicated state-level legislation, governance challenges continue to hinder effective conservation. Issues such as encroachment, pollution, weak enforcement, and institutional fragmentation reduce the functional efficiency of the wetland system and threaten its long-term resilience. Spatial analysis of land-use change and ecological degradation reinforces these concerns, showing increasing fragmentation and loss of ecological connectivity, which directly impacts ecosystem service delivery.

At the same time, emerging opportunities such as carbon trading, climate finance, and ecotourism provide promising pathways to integrate conservation with economic incentives. These mechanisms can potentially bridge the gap between ecological value and financial returns, particularly if supported by robust valuation frameworks and inclusive governance models. Community participation emerges as a critical factor in this context, given that local stakeholders are both primary beneficiaries and key managers of wetland resources. Overall, the discussion emphasizes the need for a paradigm shift from sectoral and fragmented management approaches toward integrated, ecosystem-based planning. Embedding ecosystem service valuation into urban policy, strengthening institutional coordination, and promoting participatory governance are essential for sustaining the ecological integrity and economic viability of the East Kolkata Wetlands. Such an approach not only safeguards a critical urban ecological asset but also provides a replicable model for sustainable wetland management in rapidly urbanizing regions worldwide.

Conclusion

The East Kolkata Wetlands provide invaluable ecosystem services that sustain both ecological integrity and human well-being. Their multifunctional role in wastewater treatment, food production, climate regulation, and biodiversity conservation underscores their global significance. Economic valuation of ecosystem services offers a powerful tool for integrating environmental considerations into policy planning.

However, effective implementation requires strong governance frameworks, stakeholder participation, and innovative financing mechanisms such as carbon trading and ecotourism. Ensuring the long-term sustainability of the East Kolkata Wetlands will depend on the successful integration of ecological knowledge, economic valuation, and community engagement into regional planning processes.

References

- Adhikari, S., Pal, S., Barik, A., Chakraborty, S., & Mukhopadhyay, S. K. (2021). Carbon sequestration by horticultural plants in East Calcutta Wetlands ecosystem, a Ramsar Site in India. *International Journal of Chemical and Environmental Sciences*, 2(2), 18-27.
- Basu, S., Nagendra, H., Verburg, P., & Plieninger, T. (2024). Perceptions of ecosystem services and knowledge of sustainable development goals around community and private wetlands users in a rapidly growing city. *Landscape and Urban Planning*, 244, 104989.
- Bhattacharyya, S., Pal, N., Zaman, S., & Mitra, A. (2025). Application of Python Programming for Soil Carbon Stock Assessment in the East Kolkata Wetlands: A Digital Approach to Soil Health Evaluation. *International Journal for Multidisciplinary Research*, 7(2): 1
8. <https://doi.org/10.36948/ijfmr.2025.v07i02.40652>.
- Chakraborty, A., Halder, S., Nazneen, S., & Dey, S. (2019). East Kolkata Wetlands (EKW), India: A Unique Example of Resource Recovery. *Wastewater Reuse and Watershed Management*. <https://doi.org/10.1201/9780429433986-4>.
- Chatterjee, A., Chakraborty, S., Kumar, P., Bagdi, S. S., & Meraj, G. (2025). Integrated approach to evaluate the role of wetland for disaster risk reduction and human well-being: A case study of East Kolkata wetland. *Progress in Disaster Science*, 100490.

- Chatterjee, A., Chakraborty, S., Kumar, P., Bagdi, S. S., & Meraj, G. (2025). Integrated approach to evaluate the role of wetland for disaster risk reduction and human well-being: A case study of East Kolkata wetland. *Progress in Disaster Science*, 100490.
- Das, S. (2025, January). The Transformation and Associated Ecological Problems of the East Kolkata Wetlands, West Bengal, India: Observations between 1989-2024. In *IOP conference series: Earth and environmental science* (Vol. 1443, No. 1, p. 012013). IOP Publishing.
- Dey, D., & Banerjee, S. (2013). Ecosystem and Livelihood Support: The Story of East Kolkata Wetlands. *Environment and Urbanization Asia*, 4, 325 - 337. <https://doi.org/10.1177/0975425313511158>.
- Dey, D., & Banerjee, S. (2017). Wastewater management and the east-bound growth of the city of Kolkata: A compatibility analysis. *Environment, Development and Sustainability*, 19(5), 1911-1932.
- Everard, M., Kangabam, R., Tiwari, M. K., McInnes, R., Kumar, R., Talukdar, G. H., ... & Das, L. (2019). Ecosystem service assessment of selected wetlands of Kolkata and the Indian Gangetic Delta: multi-beneficial systems under differentiated management stress. *Wetlands Ecology and management*, 27(2), 405-426.
- Ghosh, S., Rautela, R., Mitra, A. K., Choudhury, S. S., Chandra, A., Kumar, S., & Dhara, B. (2024). Exploring soil fertility dynamics and microbial flora in the east kolkata wetlands: implications for sustainable agriculture and ecosystem conservation. *Vegetos*, 1-10.
- Ghosh, S., Rautela, R., Mitra, A. K., Choudhury, S. S., Chandra, A., Kumar, S., & Dhara, B. (2024). Exploring soil fertility dynamics and microbial flora in the east kolkata wetlands: implications for sustainable agriculture and ecosystem conservation. *Vegetos*, 1-10.
- Khan, I., Gupta, D. D., & Gupta, A. (2024). Sewage treatment by Kolkata's natural wetland system. *Nature Environment and Pollution Technology*, 23(3), 1801-1816.
- Kumar, N., Chandan, N., Bhushan, S., Singh, D., & Kumar, S (2023). Health risk assessment and metal contamination in fish, water and soil sediments in the East Kolkata Wetlands, India, Ramsar site. *Scientific Reports*, 13. <https://doi.org/10.1038/s41598-023-28801-y>.
- Kumar, R. (2018). East Kolkata wetlands and the regulation of water quality. *The Wetland Book*, 1293-1299.
- Mandal, D., & Palit, D. (2025). Eco-floristic Survey on Aquatic Macrophytes from Three Mouzas of East Kolkata Wetland, West Bengal, India. *INTERNATIONAL JOURNAL OF PLANT AND ENVIRONMENT*, 11(02), 247-258.
- Mohan, R. R., Nagesh, T., Das, A., Sahu, S., Reddy, D. R., & Paturi, A. P. (2019). Physico-chemical characteristics of Nalban wetland of east Kolkata wetlands, a Ramsar site, West Bengal, India. *International Journal of Current Microbiology and Applied Sciences*, 8(04), 1264-1275.
- Mukherjee, S., Sikdar, P. K., Pal, S., & Schuett, B. (2021). Assessment of environmental water security of an Asian deltaic megacity and its peri-urban wetland areas. *Sustainability*, 13(5), 2772.
- Mundoli, S., Sanfui, A., & Nagendra, H. (2023). Pestilential or Productive? Tracking Two Centuries of Environmental Change and Current Perceptions About Ecosystem Services of the East Kolkata Wetlands. *Urbanisation*, 8(2), 143-163.
- Saha, S., Saha, T., & Basu, P. (2016). Planktons in dirty water: carbon cycling process of sewage fed fisheries in East Kolkata Wetland, India. *Wetlands*, 36(3), 415-429.
- Sen, P., Mandal, S., Ghosh, P. B., Datta, S. K., & Saha, N. C. (2024). Carbon sequestration and methane emission of East Kolkata wetland, a Ramsar site in India. *Ecological Frontiers*, 44(5), 972-980.
- Yadav, P. K., Jha, P., Joy, M. S., & Bansal, T. (2024). Ecosystem health assessment of East Kolkata Wetlands, India: Implications for environmental sustainability. *Journal of Environmental Management*, 366, 121809.

RETHINKING CONSERVATION OF TRANSBOUNDARY GRASSLAND SYSTEMS:

A CASE STUDY OF THE TERAJ-DUAR SAVANNA AND GRASSLAND ECOREGION

Dr. Chandreyi Sengupta, Senior Research Officer (PFRI)

Grasslands remain among the least adequately valued ecosystems in South Asia. Within policy discourse and administrative practice, they are frequently regarded as marginal spaces situated between forests, wetlands, and cultivated land, rather than as ecologically distinctive formations with their own structural characteristics, functional roles, and conservation value. Such a framing has had serious consequences. Where grasslands are interpreted as degraded land, management interventions predominantly focus on afforestation, eventually transforming these open ecosystems by altering their ecological character, habitat structure, and species composition. Recent scholarship has drawn attention to this long-standing problem, indicating that grasslands and allied habitats have been persistently underrepresented in conservation planning despite their major contribution to biodiversity and ecological resilience (Madhusudan & Vanak, 2022).

Despite being widely undervalued, grasslands are ecologically significant ecosystems that support distinctive biodiversity and contribute to soil stabilisation, water infiltration, runoff regulation, and nutrient cycling through extensive root systems and the turnover of herbaceous biomass.

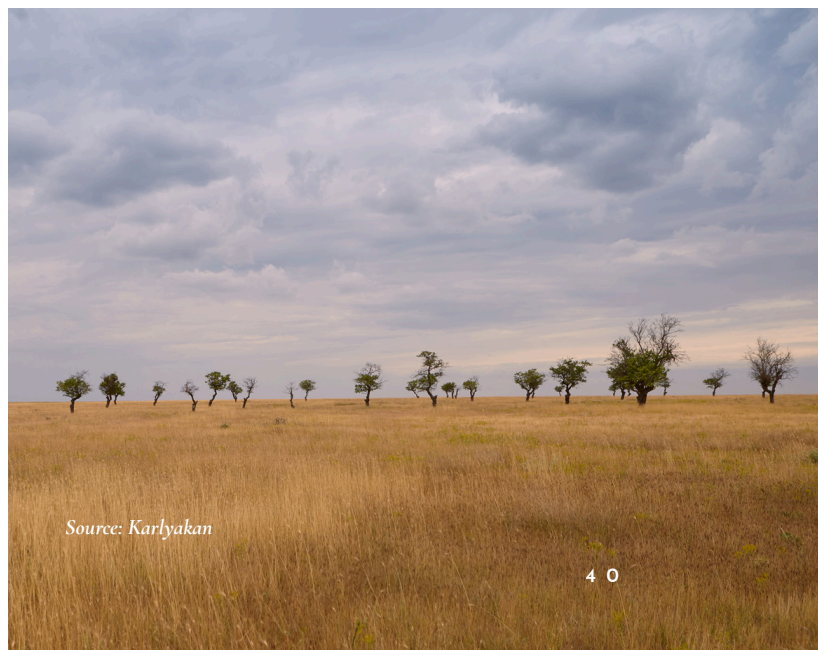
These ecological functions are closely tied to the maintenance of open grass-dominated conditions, which in many regions depend on recurrent natural and biotic processes such as fire, grazing, flooding, and geomorphological change. This is especially significant in humid or seasonally wet settings, where the spread of woody vegetation may be interpreted too readily as ecological recovery. A growing body of literature on grassy biomes has therefore cautioned against equating increases in tree cover with restoration ubiquitously. In long-established grassland systems, such assumptions can result in habitat loss rather than prevent it (Murphy et al., 2016).

These wider concerns become particularly important in the Terai-Duar Savanna and Grassland ecoregion, the lowland alluvial belt extending along the Himalayan foothills across northern India and southern Nepal. This region contains a complex floodplain mosaic in which grasslands occur alongside wetlands, riverine woodland, forest, scrub, and agricultural land. The ecological importance of this mosaic is considerable, yet available evidence indicates that grassland habitats within the Terai have undergone marked contraction in the last 3 decades.

Although grasslands constituted approximately 28% (about 1,417 sq. km) of the total area of the Terai-Duar Savanna and Grassland system in 1988–1989, their extent declined by nearly 34.4% by 2019. Expansion of woodland in several locations and, in some places, conversion into agricultural land have been documented as primary reasons for such decline. This also reflects a deeper conceptual problem in conservation planning. On both the Nepalese and Indian sides of the Terai, grasslands are acknowledged within broader habitat, corridor, and protected-area frameworks, but they are seldom centred as a distinct conservation priority. Instead, the landscape is more commonly framed through forests, wildlife movement, and land use management. This reflects a wider regional pattern in which open habitats are recognised, yet not fully institutionalised within conservation design. The result is a persistent conceptual imbalance wherein grasslands are present in policy, but rarely with the clarity or priority afforded to forests (Bannerjee et al., 2023).

This conceptual limitation becomes even more significant because the Terai is not merely a set of adjacent national landscapes, but a connected India-Nepal ecological region in which habitat processes, wildlife movement, extraction pressures, and infrastructure effects cross the international border. Joint monitoring in the Terai Arc Landscape has long recognised that the open border creates both opportunities and governance difficulties for coordinated conservation. Therefore, when both jurisdictions fail to value grasslands adequately, the consequences are not confined within either country; rather, they accumulate across a shared floodplain system (Bannerjee et al., 2023).

Transboundary conservation in the Terai has frequently been organised around flagship fauna, especially tiger, rhinoceros, and elephant movement between protected areas and corridors. That emphasis has undoubtedly produced important gains, yet it has also obscured the fact that these species are sustained by habitat processes that are harder to administer and less visible in policy discourse- periodic burning, control of woody encroachment, management of grazing pressure, maintenance of floodplain dynamics, and containment of invasive plants. Work on swamp deer distribution in the western Terai has shown that settlement pressure not only reduces available area but also narrows the ecological conditions under which grassland-dependent fauna can persist- a finding that highlights how much is lost when habitat management is neglected. Moreover, recent work from Nepal's Terai grasslands points to the spread of *Mikania micrantha* across these habitats, adding another layer of degradation to systems already under pressure from land conversion and altered management. Therefore, a transboundary landscape framework that prioritises animal passage but neglects the ecological maintenance of the grassland itself remains incomplete (Dhami et al., 2023).



Source: Karlyakan

This incompleteness is visible in the growing friction between conservation goals and infrastructure expansion across the transboundary Terai. For instance, the Hulaki highway running along the Nepal-India border intersects several biologically important corridors, including the Khata corridor linking Bardia National Park in Nepal with Katarniaghat Wildlife Sanctuary in India, the Karnali corridor in far-western Nepal, the Basanta corridor in Nepal's Kailali district near the Indian border, and the Laljhadi-Mohana corridor connecting Shuklaphanta Wildlife Reserve in Nepal with Dudhwa National Park in Uttar Pradesh, India. The same strategy warns that road expansion along both sides of the border could further weaken connectivity in these already pressured zones. Corridor assessments also record continuing encroachment, heavy livestock grazing, timber and riverbed material extraction, and habitat fragmentation across the larger Terai floodplain mosaic. These pressures do not affect grasslands alone, but they have particularly serious implications for grassland patches embedded within corridor systems, because such habitats are easily reduced, divided, or transformed when infrastructure, settlement growth, extraction, and inappropriate restoration measures intensify across the landscape. In the Basanta corridor, for instance, official planning documents report continuing pressure from encroachment, overgrazing, and overuse of forest resources, while transboundary monitoring has shown that the corridor is now broken into narrow fragments and no longer maintains effective connectivity with adjoining Indian habitats in the Dudhwa landscape. These are not merely local disturbances.

They reflect a broader failure of borderland governance in which roads, settlements, floodplain management, extraction, and conservation planning remain poorly aligned across a shared ecological region (Ghimire, 2026; Ministry of Forests and Soil Conservation, 2015).

The problems documented above point to the need for a fundamental reorientation of how grassland landscapes are understood and managed. An adequate conservation approach for the Terai grasslands of India and Nepal would therefore begin with a clearer conceptual shift. Grasslands should be treated not as residual land between more valued ecosystems, but as an integral part of the floodplain landscape. Translating that shift into practice requires addressing the specific governance failures documented across this borderland- the misalignment between infrastructure planning and conservation outcomes, the absence of coordinated habitat monitoring, and the institutional fragmentation that undermines coherent management on both sides of the border.

The most immediate gap is the absence of any joint mechanism linking infrastructure planning to conservation outcomes. The Hulaki highway was planned and monitored through a bilateral committee focused solely on road delivery, with no parallel assessment of its effects on corridor habitats. Indian forest officials have themselves flagged that road alignment in the Terai disturbs wildlife corridors and have called for alignment revision in consultation with conservation authorities, yet no formal cross-sectoral mechanism exists to enforce such consultation bilaterally (Srivastava, 2019).

Notably, although an MoU between India and Nepal in 2026 provides for smart green infrastructure in biodiversity hotspots, it contains no mechanism for reviewing the conservation impacts of infrastructure already approved or under construction across the border landscape (The Prayas India, 2026). What is needed, therefore, is a standing joint body in which infrastructure ministries on both sides are required to consult designated conservation agencies before approving road expansions, land use changes, or extraction activities in corridor zones, with grassland habitats explicitly included within the scope of that consultation.

Moreover, coordinated cross-border monitoring of grassland extent and condition does not currently exist. The Government of Nepal is working on mapping ecosystem types, including grasslands, and WWF Nepal is developing a framework for habitat management in the lowland Terai, but these remain unilateral initiatives . A shared baseline, using standardised remote sensing protocols to track grassland cover, woody encroachment, and corridor connectivity across the border, would provide the evidence base that transboundary management currently lacks. Without it, governance decisions on both sides continue to be made without a common picture of what is being lost (Rangelands Atlas, n.d.).

The third gap is institutional. In India, less than 1% of grasslands are protected under the formal conservation network, and governance is fragmented across ministries with conflicting mandates. The situation in Nepal is structurally parallel- grassland management is distributed across the Department of National Parks and Wildlife Conservation, the Department of Forests and Soil Conservation, and provincial governments, with no dedicated mandate for open habitat in either jurisdiction. Transboundary cooperation cannot be effective when neither party has internal institutional coherence on the subject being coordinated. Both countries would need to designate a nodal agency with explicit grassland responsibility before joint management protocols can be meaningfully implemented (Thapa et al., 2023).

Furthermore, research on subtropical monsoon grasslands has shown that woody encroachment is a persistent risk under conditions of high rainfall and that passive protection is unlikely to be sufficient where open habitat is to be retained- a finding that matters directly for the Terai, where legal designation alone cannot stabilise grassland condition in a productive lowland landscape shaped by human use (Thapa et al., 2023). Active management of fire regimes, grazing pressure, and invasive species, therefore, cannot remain a site-level discretion; rather, it needs to be embedded in the management plans of protected areas and corridors on both sides of the border.



What the Terai case ultimately illustrates is a problem that extends across South Asia. Grasslands in several South Asian countries, including India, are negatively affected by commitments to global goals with quantified targets of increasing tree cover, compounded by the involvement of multiple government bodies and a strong forest bias within both government bodies and nongovernmental organisations. Analysis of relevant policies of these countries also confirms that there is little in current policies on conservation action at the regional scale for open ecosystems. The Terai is among the best-documented cases of this failure, and the one where a functioning bilateral framework already exists to build upon. If the governance of this landscape cannot be reformed to improve grassland conditions alongside wildlife movement, the prospects for open ecosystems elsewhere in the region—less studied, less connected, and less institutionally supported—are considerably worse. The minimum requirement is the recognition that openness is itself an ecological attribute worthy of protection, not a condition to be corrected (Lahiri et al., 2023).

References

Banerjee, S., Das, D., Zhang, H., & John, R. (2023). Grassland-woodland transitions over decadal timescales in the Terai-Duar savanna and grasslands of the Indian subcontinent. *Forest Ecology and Management*, 530, 120764.

Dhami, B., Adhikari, B., Panthi, S., & Neupane, B. (2023). Predicting suitable habitat of swamp deer (*Rucervus duvaucelii*) across the Western Terai Arc Landscape of Nepal. *Heliyon*, 9 (6), e16639.

Ghimire, K. (2026, February 14). *Hulaki Highway stalled after 16 years amid contract cancellations and government inaction*. Ratopati

Lahiri, S., Roy, A., & Fleischman, F. (2023). Grassland conservation and restoration in India: A governance crisis. *Restoration Ecology*, 31(4), e13858.
<https://doi.org/10.1111/rec.13858>

Madhusudan, M. D., & Vanak, A. T. (2022). Mapping the distribution and extent of India's semi-arid open natural ecosystems. *Journal of Biogeography*, 50, 1377–1387.
<https://doi.org/10.1111/jbi.14471>

Ministry of Forests and Soil Conservation. (2015). *Strategy and action plan 2015–2025: Terai Arc Landscape, Nepal*. Government of Nepal

Murphy, B. P., Andersen, A. N., & Parr, C. L. (2016). The underestimated biodiversity of tropical grassy biomes. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 371(1703), Article 20150319.
<https://doi.org/10.1098/rstb.2015.0319>

Rangelands Atlas. (n.d.). *Partnerships to protect threatened animal species in the lowland Terai of Nepal*.
<https://www.rangelandsdata.org/atlas/case-studies/partnerships-protect-threatened-animal-species-lowland-terai-nepal>

Srivastava, K. (2019, May 7). *Indo-Nepal border road rides roughshod on Uttar Pradesh wildlife habitat*. Mongabay-India

Thapa, S. K., de Jong, J. F., Hof, A. R., Subedi, N., & Prins, H. H. (2023). Enhancing subtropical monsoon grassland management: Investigating mowing and nutrient input effects on initiation of grazing lawns. *Global Ecology and Conservation*, 47, e02686.

The Prayas India. (2026, February 27). *India–Nepal environmental MoU (Feb 2026): New push for transboundary ecosystem conservation*.
<https://theprayasindia.com/india-nepal-environmental-mou/>

BALANCING WASTE, WATER, AND SURVIVAL:

MANAGING RESOURCE CONFLICTS IN TRANSITIONAL WETLANDS

Ms. Ishita Maji, Department of Biotechnology, SOLB, Adamas University, Kolkata

Introduction

Transitional wetlands serve as vital interfaces between anthropogenic activity and natural ecosystems. These regions provide essential livelihoods, support critical ecological processes, and preserve biodiversity. However, rising human pressures have increasingly transformed these areas into conflict zones characterized by competing ecological and economic demands.

According to Mirzaei & Zibaei (2021), climate variations have further escalated these tensions by disrupting water supplies and altering ecosystem dynamics. Consequently, land usage in these ecosystems has become a secondary source of conflict alongside water scarcity. The capacity of wetlands to provide ecosystem services is frequently diminished by the encroachment of urban infrastructure. This is particularly critical because local populations remain heavily dependent on these regions for their economic survival.

The Convention on Wetlands (2025) notes that these conflicts continue to escalate primarily due to a lack of robust management regimes. Without a comprehensive management framework that accounts for both ecological boundaries and human needs, these transitional regions will remain susceptible to ongoing degradation.

Resource conflict in these ecosystems is fundamentally a result of conflicting uses rather than simple resource shortages.

Competing Demands and Resource Conflict

Transitional ecosystems face significant stress as several groups compete to utilize scarce resources. Within these environments, water, land, and biological productivity are critical factors for sustainable development and regional growth. This leads to an environment where sharing of resources becomes a point of concern, as presented in Table 1. To manage waste loads, urban councils often discharge untreated or partially treated effluent into the wetlands. Simultaneously, local inhabitants use these areas for agriculture, irrigation, and fishing. The two types of uses result in an inherent conflict due to the fact that one group considers the wastewater to be their means of disposing of waste, while another uses it as a source of productivity. According to Mirzaei & Zibaei (2021), variations in climate have resulted in a further escalation of such conflicts through influencing the water supply as well as ecosystem processes.

Land usage in transitional ecosystems becomes a source of conflict in addition to water. Wetlands' ability to carry out ecological services is frequently diminished by the encroachment of growing urban infrastructure. Conflict arises because the people living in these regions are dependent on these regions for their economic activities.

According to the Convention on Wetlands (2025), these conflicts have continued to escalate owing to the fact that there are no management regimes in place.

These transitional regions will always be subject to degradation if there is no management framework in place, taking into account both ecological boundaries and human needs. The resource conflict in transitional ecosystems arises because of conflicting uses and not simply shortages.

Case Insight: East Kolkata Wetlands

East Kolkata Wetlands offer an excellent case study of transitional ecosystem functioning in the face of conflicting resource use. The local population makes use of urban effluents in sewage-fed aquaculture and agriculture, turning wastage into a resource-based economic activity.

As pointed out by Yadav et al. (2025), this constitutes a successful example of resource reuse through natural processes, facilitating human practices. Yet, urbanisation, higher levels of pollution, and irregular land use pose a threat to the future functioning of the system. Several parties are dependent on one particular resource at once. Municipalities treat their sewage with the help of wetlands, while communities use the water in the wetlands for fishing purposes and farming activities.

Table 1. Key Resource Conflicts and Potential Mitigation Approaches in Transitional Wetlands

Resource	Stakeholders Involved	Nature of Conflict	Potential Mitigation Approach
Water (Wastewater)	Urban authorities, local communities, ecosystem	Disposal vs reuse; pollution vs productivity	Controlled wastewater treatment and reuse systems
Land	Urban developers, local communities, and conservation bodies	Land conversion vs ecosystem preservation	Land-use regulation and wetland protection policies
Biomass (algae, fish)	Fisherfolk, farmers, and ecological systems	Overexploitation vs biodiversity conservation	Sustainable harvesting and ecosystem monitoring
Nutrients (organic waste)	Agriculture, wastewater systems, and the ecosystem	Excess nutrient load vs ecological balance	Nutrient recovery and circular utilisation approaches

Such dependency results in continuous conflicts regarding the utilization of the resource in the waste treatment process and for the benefit of communities. With rising levels of pollutants in the wetland, the water becomes polluted, which affects the fish population and biodiversity in wetlands. Hence, such ecosystems find it hard to provide their two important functions. As stated by the Convention on Wetlands (2025), uncontrolled pollution in transitional ecosystems results in degradation and loss of ecosystem services. Consequently, the East Kolkata Wetlands provide an example of the key principle that transitional ecosystems are capable of performing ecological as well as anthropological roles, but only up to a certain point. The moment that limit is surpassed, usage patterns shift from cooperation to competition.

Wastewater as a Contested Resource

The role of wastewater in transitional ecosystems is twofold. Firstly, it is the addition of pollutants to worsen the quality of the environment. Secondly, it contributes nutrients necessary for the growth of crops and other living things. In light of these statements, de Campos and Soto (2024) explain that it is possible to clean up this water for further use due to the existence of constructed wetlands, and it can result in better resource recovery and environmental sustainability. Nonetheless, unregulated release may disrupt ecosystem balance, especially when water treatment plants cannot handle wastewater adequately.

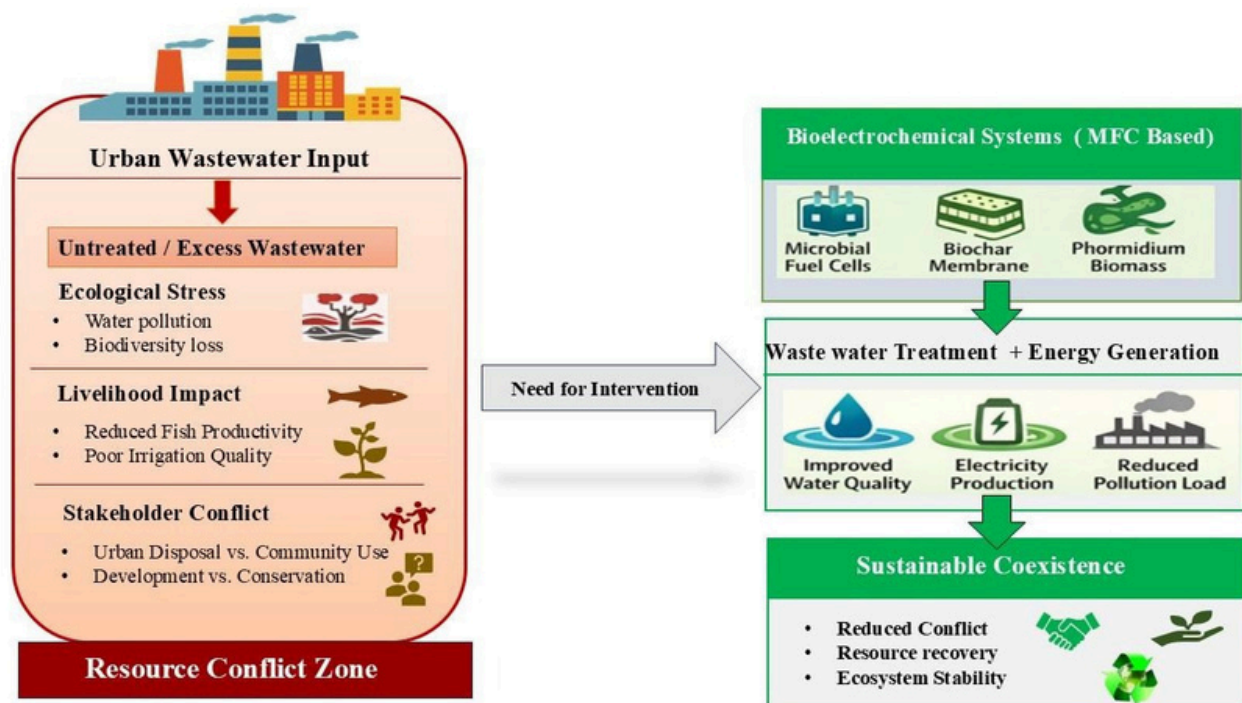


Figure 1. Conceptual representation of wastewater-derived resource conflict and its mitigation through bioelectrochemical systems.

Biotechnological Pathways for Conflict Mitigation

Biotechnology offers helpful solutions that can transform resource disputes into sustainable possibilities. Zhang et al. (2024) claim that integrating microbial fuel cells with artificial wetlands improves wastewater treatment efficiency and enables energy recovery, especially when paired with biochar made from sewage sludge. These integrated systems show how waste streams may be transformed into useful resources. For example, microbial fuel cells (MFCs) use microbial metabolic activity to break down organic materials in wastewater and produce power, which lowers pollution levels. Additionally, the use of membranes based on biochar enhances filtering effectiveness and promotes microbial activity. Utilising algal biomass, like *Phormidium* sp., enhances water filtration and nutrient absorption, which improves system efficiency. These techniques demonstrate how biotechnological interventions may alleviate environmental stress while also balancing the requirements of diverse stakeholders, resulting in more sustainable management of transitional ecosystems.

Towards a Circular and Sustainable System

Circular bioeconomy is one of the strategies that can be utilized in the reduction of resource conflicts in transitional ecosystems. This involves the recycling of waste materials for reuse. According to Monzón-Reyes et al.(2025), the integration of water treatment with the recovery of resources can help increase sustainability. This strategy will reduce resource consumption since waste products can be converted to usable forms and energy.

Policy and Community Dimensions

Management of transitional ecosystems is not just about ecology and technology but also about effective governance and involvement of the community.

As seen from the experiences of many wetland systems, piecemeal and weakly enforced approaches enable the continuation of unsustainable activities and exacerbate resource disputes. The Convention on Wetlands (2025) stipulates that policymakers have to regard wetlands as socio-ecological systems with significant production capacity and not merely empty spaces where building is allowed. Nevertheless, in reality, the focus of authorities on urbanization and construction means that there is insufficient regulation of wastewater, encroachment, and ecosystem functions. From the community's perspective, there is an important role for the community to play in maintaining the transitional ecosystems. For example, in transitional ecosystems like East Kolkata Wetlands, people control the use of wastewater in fishing and farming.

As discussed by the authors Barman et al., (2025), community-based management is essential as it will lead to positive outcomes concerning the conservation efforts in that area. This is because, in the management and policymaking processes, community members are always involved, which leads to successful outcomes but when they are not involved, then the result is poor performance and conflict. Poor performance in policies is also brought about by poor coordination between innovations and environmental management.

There is no proper coordination between innovations and environmental management. To cope with such challenges, the authorities should adopt a comprehensive approach that involves environmental conservation, technological innovations, and community involvement. The first step involves improving legislation about wetlands, controlling sewage releases, and implementing decentralized water treatments. The second step involves encouraging community-based programs through education, incentive schemes, and participatory plans. As per the existing sustainability theories, the most effective approach to resolving resource-related conflicts is collaborative governance, wherein scientists, politicians, and the communities work together (Monzón-Reyes et al., 2025). It provides practicality, inclusiveness, and adaptability of policies to be developed. To summarize, resolving resource-related conflicts in transitional environments necessitates the transition from the conventional hierarchical approach to adaptive and inclusive management. It will allow adopting communities' significance to be incorporated into the policies by means of technological progress.

Conclusion

The transitional ecosystem serves as an example of a dynamic system in which the demands of humans clash with the constraints of nature, leading to resource-related disputes. Resolving such disputes necessitates moving away from a linear mode of resource utilization towards a more integrated and cyclical mode of action. Biotechnological inventions like microbial fuel cells provide feasible solutions in that they convert wastewater into useful resources.

References

- Convention on Wetlands. (2025). *Global Wetland Outlook 2025: Valuing, conserving, restoring and financing wetlands*. Gland, Switzerland: Secretariat of the Convention on Wetlands.
- Monzón-Reyes, B. L., González-Moreno, H. R., Month, A. E. Á., Peralta Vega, A. J., Ballut-Dajud, G., & Sandoval Herazo, L. C. (2025). Wastewater Management Strategies in Rural Communities Using Constructed Wetlands: The Role of Community Participation. *Earth*, 6(2), 18.
- Barman, A., Rajak, F., & Jha, R. (2025). Integrating Traditional Knowledge Systems for Wetland Conservation and Management: A Critical Analysis. *Nature Environment & Pollution Technology*, 24(1).
- Peh, K., & Clark, C. (2025, July). Case study 4. Ecosystem service valuation of peatland restoration in the UK. Convention of Wetlands.
- Zhang, F., Shen, C., Zhao, Y., Zhang, S., Wang, Y., Ji, B., ... & Zhang, J. (2024). An integrated constructed wetland-Microbial fuel cell system with sewage sludge-biochar to enhance treatment and energy recovery efficiencies. *Chemical Engineering Journal*, 486, 150431.
- de Campos, S. X., & Soto, M. (2024). The use of constructed wetlands to treat effluents for water reuse. *Environments*, 11(2), 35.
- Yadav, P. K., Jha, P., Joy, M. S., Bansal, T., Rawat, P., Begam, S., & Singh, A. K. (2025). Investigating the role of policies in the sustainable management of East Kolkata wetlands. *Discover Global Society*, 3(1), 79.
- Mirzaei, A., & Zibaei, M. (2021). Water conflict management between agriculture and wetland under climate change: Application of economic-hydrological-behavioral modelling. *Water Resources Management*, 35(1), 1-21.

ASSESSING GEODIVERSITY INDEXING AS A TOOL FOR GEOCONSERVATION OF WETLAND ECOSYSTEMS

Dr. Krishnanand¹, Associate Professor, School of Humanities & social Sciences, Sharda University

Dr. Vipin Solanki², Assistant Professor of Geography, Sharda University

Abstract

Wetlands are dynamic ecological systems whose structure and functioning are fundamentally governed by geological, geomorphological, and hydrological processes. Despite their ecological significance, traditional conservation approaches have largely remained centred on biodiversity, often overlooking the physical foundation that sustains these ecosystems. This paper assesses geodiversity indexing as a scientific and methodological framework for the geoconservation of wetland ecosystems. It traces the conceptual evolution of geodiversity assessment and critically examines major indexing approaches, including grid based, weighted, terrain based, multi criteria, and integrated field-based methods. Drawing on insights from the Trans Himalayan region, the study demonstrates how geodiversity influences wetland formation, ecological resilience, and landscape transitions under environmental change. The paper argues that incorporating geodiversity indexing into geoconservation planning enables a more comprehensive and process-oriented approach to wetland management, thereby enhancing long term sustainability.

Keywords: Geodiversity, Wetlands, Geodiversity Indexing, Geoconservation, Trans Himalaya

Introduction

Wetlands occupy a critical position within the Earth system as transitional environments where terrestrial and aquatic processes intersect. These ecosystems provide a wide range of services, including hydrological regulation, carbon sequestration, nutrient cycling, and biodiversity support. However, their existence and persistence are deeply rooted in the physical structure of the landscape, shaped by geological, geomorphological, and hydrological processes that operate across multiple spatial and temporal scales.

Conventional conservation frameworks have predominantly focused on biological diversity, often neglecting the abiotic foundation that governs ecosystem functioning. This has led to a fragmented understanding of wetlands, where surface level indicators such as vegetation and water extent are prioritised, while underlying geomorphic and hydrological processes remain underexplored. In this context, geodiversity emerges as a critical concept that bridges this gap by emphasising the diversity of the physical environment and its role in sustaining ecosystems (Gray, 2013).

Geodiversity is not merely a static inventory of rocks and landforms but a dynamic system that influences habitat distribution, regulates water flow, and enhances ecological resilience.

In wetland environments, even minor variations in elevation, slope, and substrate can significantly alter hydrological conditions and ecosystem behaviour. Recognising these interactions is essential for developing a more integrated approach to conservation.

Geodiversity indexing offers a quantitative framework to assess and map the spatial variability of abiotic features. By translating landscape complexity into measurable indices, it enables a deeper understanding of ecosystem processes and supports evidence-based decision making. In fragile regions such as the Trans Himalaya, where extreme environmental conditions and human adaptation are closely linked to the landscape, geodiversity plays a central role in shaping both ecological and socio-economic systems (Krishnanand, 2019; Krishnanand, 2026). The cold desert environment, characterised by glacial landforms, periglacial processes, and seasonal hydrological regimes, provides a compelling context for examining the role of geodiversity in wetland formation and conservation.

Conceptual Foundations of Geodiversity and Geoconservation

The concept of geodiversity has evolved from early geomorphological studies that recognised the scientific and cultural significance of landforms (Panizza, 2001). Over time, this perspective has expanded to encompass the broader diversity of geological, geomorphological, soil, and hydrological features that constitute the physical environment. The transition from qualitative appreciation to quantitative assessment was marked by the work of Serrano and Ruiz Flaño (2007), who introduced geodiversity as a measurable concept.

Their framework enabled the systematic analysis of landscape heterogeneity through composite indices. Subsequent developments incorporated spatial analysis techniques (Serrano et al., 2009) and terrain-based modelling (Hjort and Luoto, 2010), further refining the methodology. Geoconservation has emerged as an applied dimension of geodiversity, focusing on the protection and sustainable management of abiotic features. It recognises that conserving geodiversity is essential not only for preserving geological heritage but also for maintaining ecosystem processes and services. In wetland systems, geoconservation involves safeguarding the geomorphic and hydrological processes that sustain these ecosystems.

Recent studies emphasise the integration of geodiversity into conservation planning, highlighting its role in enhancing ecosystem resilience and supporting sustainable development (Zwoliński et al., 2018). In the Trans Himalayan context, geoconservation is closely linked with human adaptation, geotourism, and livelihood systems, underscoring the need for integrative approaches (Krishnanand, 2019; Krishnanand, 2026).

Geodiversity Indexing Approaches in Wetland Ecosystems

Wetlands are inherently geomorphological systems, and their analysis requires approaches that capture both spatial variability and process dynamics. Geodiversity indexing provides a structured framework for such analysis.

Simple Grid Based Geodiversity Index

The grid-based approach introduced by Serrano and Ruiz Flaño (2007) represents a foundational method for quantifying geodiversity.

The grid-based approach introduced by Serrano and Ruiz Flaño (2007) represents a foundational method for quantifying geodiversity. By dividing the landscape into uniform spatial units and counting the diversity of abiotic elements within each unit, it reveals patterns of landscape heterogeneity.

In wetland environments, particularly floodplains, this method captures the mosaic of geomorphic features such as levees, oxbow lakes, and depressions that influence water distribution. However, its limitation lies in treating all variables equally, which may not fully reflect the dominance of hydrological processes.

Table 1. Simple Grid Based Geodiversity Index Methodological Flow

Stage	Process	Description	Output
Grid Creation	Spatial division	Divide landscape into equal cells	Grid units
Data Overlay	Mapping	Map lithology, landforms, soils	Thematic layers
Diversity Count	Analysis	Count features per cell	Diversity values
Classification	Zonation	Group into classes	Geodiversity zones
Mapping	Visualisation	Display spatial patterns	Index map

Source: Authors

Weighted Geodiversity Index

The weighted approach developed by Serrano et al. (2009) refines the grid method by assigning relative importance to variables. In wetland systems, hydrological parameters are given higher weights due to their central role in ecosystem functioning.

This approach enhances ecological realism and is particularly useful in geoconservation planning, as it highlights zones where key physical processes sustain wetland ecosystems.

Table 2. Weighted Geodiversity Index Methodological Flow

Stage	Process	Description	Output
Variable Selection	Identification	Select key parameters	Dataset
Weight Assignment	Ranking	Assign weights using Analytic Hierarchy Process (AHP)	Weighted variables
Standardisation	Normalisation	Scale data uniformly	Standard layers
Overlay Analysis	Integration	Combine variables	Composite index
Zonation	Classification	Identify priority zones	Geoconservation map

Source: Authors

Terrain Based Geodiversity Index

The terrain-based approach (Hjort and Luoto, 2010) utilises digital elevation models (DEM) to derive geomorphometric parameters such as slope and curvature. These parameters capture micro topographic variations that control water accumulation.

In wetlands, such variations are critical in determining the location and persistence of water bodies. This method is particularly effective in mountainous regions like the Trans-Himalaya, where terrain complexity shapes hydrological processes.

Table 3. Terrain Based Geodiversity Index Methodological Flow

Stage	Process	Description	Output
DEM Collection	Data acquisition	Obtain elevation data	DEM
Terrain Analysis	Extraction	Derive slope, curvature	Terrain variables
Mapping	Modelling	Generate terrain maps	Layers
Index Calculation	Integration	Combine variables	Terrain index
Interpretation	Identification	Detect wetland zones	Potential wetlands

Source: Authors

Multi Criteria Geodiversity Index

The multi criteria approach (Zwoliński et al., 2018) integrates multiple datasets using decision making frameworks. It allows for the inclusion of both physical and socio ecological variables, providing a holistic understanding of landscapes.

In wetland systems, this method is valuable for assessing vulnerability and resilience by combining geomorphic, hydrological, and land use factors.

Table 4. Multi Criteria Geodiversity Index Methodological Flow

Stage	Process	Description	Output
Criteria Selection	Identification	Select variables	Criteria set
Weighting	Analysis	Apply Multi-Criteria Decision Analysis (MCDA)	Weighted criteria
Data Integration	Overlay	Combine datasets	Composite layers
Index Generation	Calculation	Produce index	Geodiversity map
Evaluation	Zonation	Classify diversity levels	Planning zones

Source: Authors

Integrated Field Based and Geographic Information System (GIS) Supported Index

The integrated approach combines field observations with GIS analysis to capture the interaction between geodiversity and human systems (Krishnanand, 2019; Krishnanand, 2026). In the Trans Himalayan region, this method reveals how geomorphic features influence livelihoods, water use, and geotourism. By incorporating local knowledge, it provides a more grounded and context specific understanding of wetland ecosystems.

Table 3.5 Integrated Field Based and GIS Supported Index Methodological Flow

Stage	Process	Description	Output
Field Survey	Observation	Study landforms and hydrology	Field data
Community Input	Integration	Collect local knowledge	Socio data
GIS Mapping	Integration	Combine datasets	GIS layers
Analysis	Assessment	Study interactions	Integrated index
Application	Planning	Link geoconservation and livelihoods	Strategy

Source: Authors

Wetlands in Transition: A Geodiversity Perspective

Wetlands across diverse geographical settings are increasingly experiencing transformation under the combined influence of climate change, land use modifications, and expanding infrastructural development. These transformations are not merely surface level alterations; they reflect deeper shifts in the geomorphic and hydrological processes that sustain wetland ecosystems. Changes in precipitation regimes, rising temperatures, and altered runoff patterns are modifying sediment transport, groundwater recharge, and surface water dynamics, thereby influencing the spatial extent and ecological functioning of wetlands. From a geodiversity perspective, wetlands are highly sensitive landscape units, where even subtle changes in terrain, substrate, or hydrological pathways can lead to significant ecological consequences.

Land use changes such as urban expansion, agricultural intensification, and road construction often disrupt natural drainage systems and modify sediment regimes, resulting in wetland fragmentation or degradation. Similarly, infrastructural interventions can alter slope stability, channel morphology, and water flow, thereby affecting the long-term sustainability of wetland systems.

Geodiversity indexing provides a critical analytical lens to understand these transformations by capturing variations in landscape complexity and process interactions. As illustrated in Figure 1, the methodological flow integrates geodiversity components, spatial data inputs, and multiple indexing approaches within a GIS based analytical framework to generate a comprehensive understanding of landscape heterogeneity.

This structured process enables the identification of relationships between abiotic diversity and wetland dynamics, offering insights that extend beyond conventional biodiversity-based assessments.

In high altitude environments such as the Trans Himalaya, these dynamics become even more pronounced. The region is characterised by glacial and periglacial processes that play a central role in shaping landforms and controlling hydrology. Accelerated glacial retreat, driven by rising temperatures, is altering meltwater regimes and sediment fluxes, leading to the formation of new wetlands in some areas while causing the shrinkage or disappearance of others. Periglacial processes, including freeze thaw cycles and slope instability, further influence terrain dynamics and water distribution. These changes not only affect ecological systems but also have direct implications for local communities that depend on wetlands for water, grazing, and seasonal livelihoods (Krishnanand, 2026).

Understanding wetlands in transition therefore requires moving beyond isolated analyses of physical or biological components towards an integrated perspective that recognises the interdependence of geodiversity and socio ecological systems.

The interaction between landscape processes and human activities is particularly significant in fragile environments, where local adaptation strategies are closely tied to environmental conditions. Incorporating geodiversity indexing into this framework enables a more comprehensive understanding of wetland dynamics by linking physical processes with human responses.

Such an approach is essential for developing adaptive geoconservation strategies that can respond to ongoing environmental change. By identifying areas of high geomorphic sensitivity and hydrological importance, geodiversity-based assessments can inform targeted conservation interventions, sustainable land use planning, and community-based management practices. In this way, geodiversity indexing not only enhances scientific understanding but also contributes to the long-term resilience and sustainability of wetland ecosystems.

Concluding Remarks

Geodiversity indexing constitutes the foundational framework upon which wetland ecosystems are structured and sustained. Yet, it continues to remain marginal within mainstream geoconservation discourse. This imbalance has limited the effectiveness of conservation strategies, which often focus on visible biological components while overlooking the underlying physical processes that regulate ecosystem dynamics.

The evolution of geodiversity indexing represents a significant shift towards integrative, process-based approaches in environmental science. It is not merely a methodological advancement but a necessary analytical tool that enables the systematic quantification of abiotic diversity and its spatial expression. By capturing variations in geomorphology, hydrology, and terrain complexity, geodiversity indexing provides deeper insights into wetland formation, functioning, and transformation under environmental stress.

In the context of accelerating climate change and anthropogenic pressures, geodiversity indexing becomes indispensable for identifying vulnerable landscapes, prioritising conservation zones, and anticipating future ecosystem responses. It allows geoconservation to move beyond reactive measures towards proactive, evidence-based planning that is grounded in the physical reality of landscapes.

Integrating geodiversity indexing into policy frameworks and planning processes is therefore not simply desirable but essential.

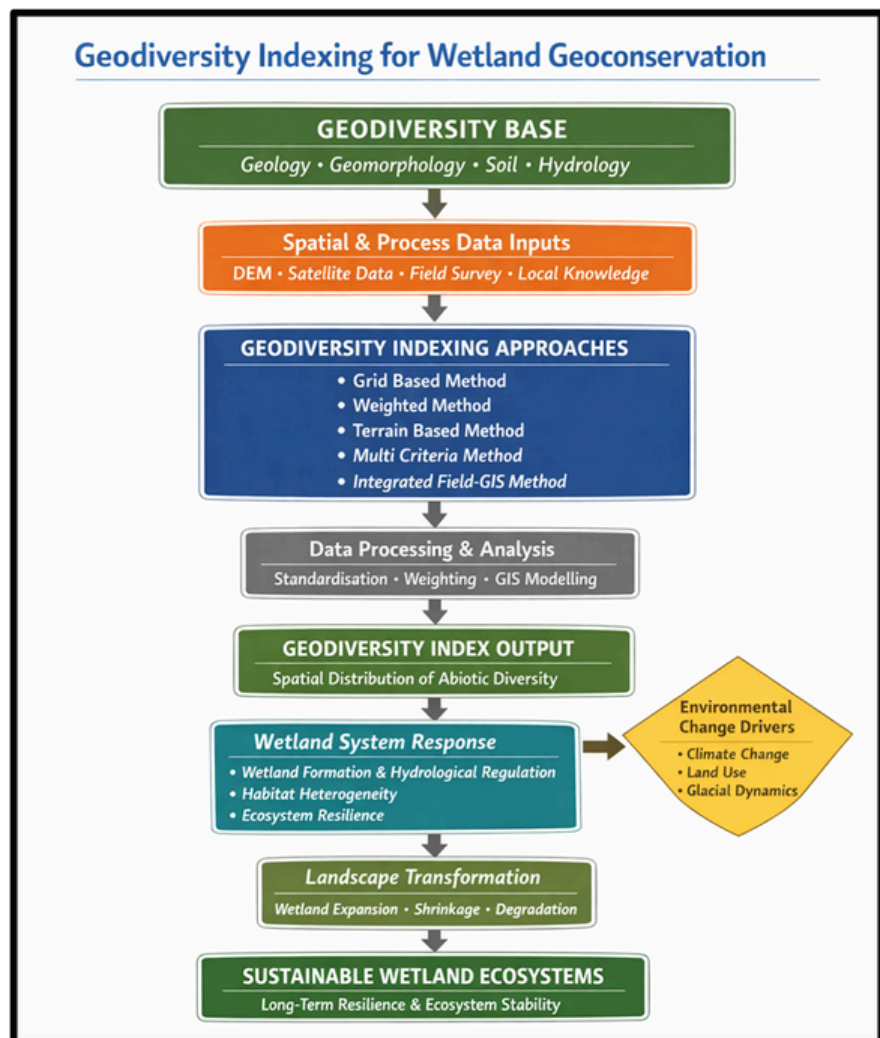


Figure 1. Methodological Flow for Geodiversity Indexing

It ensures that conservation strategies address both the visible and invisible dimensions of ecosystems, thereby enhancing long term resilience and sustainability. In this regard, geodiversity indexing emerges as a critical bridge between scientific understanding and practical geoconservation, offering a more comprehensive pathway for safeguarding wetland ecosystems in a rapidly changing world.

References

- Panizza, M. (2001). Geomorphosites: Concepts, methods and examples of geomorphological survey. *Chinese Science Bulletin*, 46, 4–6.
- Serrano, E., & Ruiz Flaño, P. (2007). Geodiversity: A theoretical and applied concept. *Geomorphology*, 86, 132–141.
- Serrano, E., Ruiz Flaño, P., & Arroyo, P. (2009). Geodiversity assessment in a rural landscape. *Memorie Descrittive della Carta Geologica d'Italia*, 87, 173–180.
- Hjort, J., & Luoto, M. (2010). Geodiversity of high latitude landscapes. *Geomorphology*, 115, 109–116.
- Gray, M. (2013). *Geodiversity: Valuing and conserving abiotic nature*. Wiley Blackwell.
- Krishnanand. (2019). Interface of geodiversity and geotourism in Lahaul and Spiti. *Landform Analysis*, 38, 41–54.
- Zwoliński, Z., Najwer, A., & Giardino, M. (2018). Methods for assessing geodiversity. In *Geoheritage*. Elsevier.
- Krishnanand. (2026). *Exploring geodiversity in Indian Trans-Himalaya: A geographical perspective*. Springer Nature Switzerland. <https://doi.org/10.1007/978-3-032-15042-4>

GRASSLANDS AS SOCIO- ECOLOGICAL SYSTEMS:

BIODIVERSITY, TRADITIONAL LIVELIHOODS, AND CONTEMPORARY PRESSURES

Mr. Sujay Bhattacharjee, Research Assistant (PFRI)

Grasslands cover almost 40% of the terrestrial biosphere of the Earth's land surface and support rich biodiversity, including a wide variety of plant and animal species (Buisson, et al., 2022; Dipolo 2020). Dominated by grasses and other herbaceous vegetation, these ecosystems are shaped by climatic factors, fire, grazing, and soil conditions, which limit the growth of woody plants (Dipolo 2020). Grasslands occur across diverse regions except extreme environments such as polar and high-altitude zones. They play a crucial role in sustaining livelihoods, particularly through livestock grazing, and have supported human societies for centuries. Today, they remain essential for agriculture and rural economies, especially in developing regions where around 68% of global grasslands is found (Boval & Dixon 2012).

Grasslands are primarily shaped by climate, especially temperature and rainfall, where limited moisture, seasonal drought, and cold conditions restrict dense forest growth and prevent desert formation, sustaining open herbaceous vegetation (Petermann & Buzhdygan, 2021). Grasslands are broadly classified into temperate and tropical-subtropical types, with additional occurrence in montane and arid regions. Temperate grasslands-such as the Eurasian Steppe, Great Plains, Pampas, and Patagonian Steppe-are shaped by cold winters, warm summers, and fertile soils, leading to extensive agricultural conversion (Petermann & Buzhdygan, 2021; Bardgett, et al., 2021). Tropical and subtropical grasslands, including the Serengeti, Cerrado, and Llanos, occur across Africa, Australia, South America, Asia, and North America, characterized by warm climates and seasonal rainfall with scattered trees (Dixon, et al. 2014; Yan, et al. 2023; Buisson, et al., 2022). Montane grasslands in the Himalayas, Andes, and Alps occur at high elevations, while arid grasslands in the Sahel and Central Asia represent transitional ecosystems between grasslands and deserts (Petermann & Buzhdygan, 2021; Bardgett, et al., 2021; Yan, et al. 2023).



Source: Mr. Sujay Bhattacharjee

Grasslands constitute one of the most extensive terrestrial biomes, supporting diverse ecological processes and long-standing human-environment interactions (Wu, et al. 2023; Lan, et al. 2020). Across regions such as the Serengeti Plains, Pampas, Campos Sulinos, Llanos, Great Plains, and Eurasian Steppe, indigenous and pastoral communities historically developed adaptive livelihood systems intricately aligned with ecological variability (Qin, et al, 2022; Wang, et al., 2025). Traditional societies such as the Maasai, Samburu, Mapuche, Guarani, Lakota, and Mongols practiced mobility-based pastoralism, hunting, and mixed subsistence strategies. These systems were ecologically sustainable, relying on seasonal migration, controlled grazing, and deep knowledge of vegetation cycles, water availability, and wildlife behavior. For instance, African pastoralists synchronized livestock movement with rainfall gradients, while Great Plains tribes depended on bison migrations, and Eurasian nomads adapted to climatic extremes through transhumance (Salim, et al., 2023; Lushombo, 2025).

However, contemporary grassland ecosystems are undergoing rapid degradation due to intensified human interventions. The expansion of commercial agriculture, monocropping, mining, infrastructure development, and urbanization has significantly altered natural grassland dynamics. In regions like the Pampas and Campos, large-scale soybean cultivation and mechanized ranching have replaced diverse native grass species, leading to habitat homogenization and soil degradation.

Similarly, in the Eurasian Steppe and African savannas, sedentarization policies and land privatization have restricted pastoral mobility, disrupted traditional grazing cycles and increased pressure on limited rangelands (Liu, et al., 2019; Gang, et al, 2014).

Environmental changes further exacerbate these challenges. Climate variability, including altered precipitation patterns and increased frequency of droughts, has intensified grassland vulnerability. In the Llanos and African savannas, erratic rainfall disrupts pasture availability, while in temperate grasslands like the Great Plains, extreme weather events and land-use intensification accelerate soil erosion and biodiversity loss. Additionally, invasive species, overgrazing in restricted areas, and fire regime alterations contribute to ecosystem instability (Ratcliffe, et al., 2023).

Indian grasslands represent crucial ecosystems that provide a variety of ecological services and support. Biodiversity conservation, yet they are currently facing significant threats from both anthropogenic and natural sources (Dey, et al., 2024). These ecosystems are characterized by predominantly herbaceous vegetation with minimal shrub cover, maintained by factors such as fire, grazing, harvesting, aridity, and low-temperature stress. In India, grasslands are often neglected and treated as wastelands, remaining unprotected, highly fragmented, and poorly understood, which contributes to a loss of unique biodiversity and livelihoods (Saha et al., 2024).

India exhibits diverse grassland ecosystems, including tropical dry grasslands of the Deccan Plateau, semi-arid grasslands in Rajasthan and Gujarat, montane Shola systems in the Western Ghats, and floodplain grasslands of the Terai-Duar. The Thar Desert supports some of the most significant grassland habitats, hosting threatened species such as the Great Indian Bustard, Houbara Bustard, and Blackbuck. (Islam, et al., 2011). The Nilgiri Biosphere Reserve also exhibits significant grass diversity, with 412 grass taxa, of which 92 are endemic to India, including 14 species strictly endemic to the NBR itself (Anusuba, et al., 2023). India has about 266 genera and 1200 species of grasses, with approximately 360 grass taxa being endemic (Jain, 2024). Despite their ecological importance, Indian grasslands are highly vulnerable and degraded. A significant portion of India's grasslands has been transformed into croplands, plantations, or infrastructure. Invasive species such as *Prosopis juliflora* and *Parthenium hysterophorus* dominate large areas, leading to declines in soil fertility and seed bank diversity. The erosion of traditional pastoral knowledge is weakening sustainable grassland management. Biodiversity loss is intensified by fragmentation, declining pollinator and granivore populations, vegetation homogenization, and significant habitat decline, such as a 57% reduction in the Gangetic Plains grasslands between 1985 and 2015. (Paul, et al., 2023).

The cumulative effect is a feedback loop where ecological degradation and socio-economic marginalization reinforce each other. As traditional practices decline, sustainable land stewardship systems are replaced by extractive and short-term land-use models, further accelerating biodiversity loss. Yet, evidence suggests that revitalizing indigenous knowledge systems and integrating them with modern conservation strategies can enhance grassland resilience.

References:

- Buisson, E., Archibald, S., Fidelis, A., & Suding, K. (2022). Ancient grasslands guide ambitious goals in grassland restoration. *Science*, 377, 594 - 598.
<https://doi.org/10.1126/science.abo4605>.
- Dipaolo, D. (2020). Grassland and Shrublands —An Overview. .
<https://doi.org/10.1016/b978-0-12-409548-9.12456-x>.
- Petermann S. Jana & Buzhdygan Y. Oksana (2021). Grassland Biodiversity. *Current Biology* 31, R 1141 – R1224.
- Boval M & Dixon R. M. (2012). The importance of grasslands for animal production and other functions: a review on management and methodological progress in the tropics. *Animal*, 2012, 748-762.
- .Wu, J., Zhou, D., Peng, C., & Jiang, G. (2023). Pastoral household natural resource dependence and contributions of grassland to livelihoods: A case study from the Tibetan Plateau in China. *Journal of Cleaner Production*.
<https://doi.org/10.1016/j.jclepro.2023.136751>.
- Lan, X., Zhang, Q., Xue, H., Liang, H., Wang, B., & Wang, W. (2020). Linking sustainable livelihoods with sustainable grassland use and conservation: A case study from rural households in a semi-arid grassland area, China. *Land Use Policy*, 105186.
<https://doi.org/10.1016/j.landusepol.2020.105186>.



Source: Mr. Sujay Bhattacharjee, PFRI

- Qin, Z., Haili, X., Xiao, L., Luwei, D., Bojie, W., Cui, F., & Tang, H. (2022). Livelihood vulnerability of pastoral households in the semiarid grasslands of northern China: Measurement and determinants. *Ecological Indicators*. <https://doi.org/10.1016/j.ecolind.2022.109020>.
- Wang, Z., Xue, Z., Zhang, X., Yan, H., & Liu, G. (2025). Adaptive Capacity to Climate Change in Pastoral Areas. *Sustainability*. <https://doi.org/10.3390/su17031337>.
- Salim, J., Anuar, S., Omar, K., Mohamad, T., & Sanusi, N. (2023). The Impacts of Traditional Ecological Knowledge towards Indigenous Peoples: A Systematic Literature Review. *Sustainability*. <https://doi.org/10.3390/su15010824>.
- Lushombo, L. (2025). Ecological Sustainability for “Life on Land”: Wellspring of Indigenous Knowledge. *Religions*. <https://doi.org/10.3390/rel16030311>.
- Liu, Y., Zhang, Z., Tong, L., Khalifa, M., Wang, Q., Gang, C., Wang, Z., Li, J., & Sun, Z. (2019). Assessing the effects of climate variation and human activities on grassland degradation and restoration across the globe. *Ecological Indicators*. <https://doi.org/10.1016/j.ecolind.2019.105504>.
- Gang, C., Zhou, W., Chen, Y., Wang, Z., Sun, Z., Li, J., Qi, J., & Odeh, I. (2014). Quantitative assessment of the contributions of climate change and human activities on global grassland degradation. *Environmental Earth Sciences*, 72, 4273–4282. <https://doi.org/10.1007/s12665-014-3322-6>.
- A, S., Xie, B., Wuliji, M., & Zhao, L. (2024). Integrating Traditional Ecological Knowledge into Land Use and Land Cover Change Assessments, Pastoralist Communities in Northwest Inner Mongolia China. *Land*. <https://doi.org/10.3390/land13121979>.
- Mistry, J., & Berardi, A. (2016). Bridging indigenous and scientific knowledge. *Science*, 352, 1274 - 1275. <https://doi.org/10.1126/science.aaf1160>.
- Ratcliffe, H., Kendig, A., Vacek, S., Carlson, D., Ahlering, M., & Dee, L. (2023). Extreme precipitation promotes invasion in managed grasslands. *Ecology*, e4190. <https://doi.org/10.1002/ecy.4190>.
- Dey, R., Sharma, S. B., & Thakkar, M. G. (2024). Maximising ecological value and assessing land suitability for sustainable grassland management in Asia’s largest tropical grassland, Western India. *Scientific Reports*, 14(1). <https://doi.org/10.1038/s41598-024-62775-9>
- Saha, K., Chandran, M., Negi, R., & Guleri, S. (2024). Challenges and Opportunities in Conserving Grassland Ecosystems of Western Himalayan region. *Phytotalks*, 1(2), 131–142. <https://doi.org/10.21276/pt.2024.1.2.7>
- Islam, M. Z., & Rahmani, A. R. (2011). Thar Desert, Rajasthan, India: anthropogenic influence on biodiversity and grasslands. *Biodiversity*, 12(2), 75–89. <https://doi.org/10.1080/14888386.2011.585931>
- Anusuba, V., Murugesan, M., Nagaraju, S., Swamy, J., Tharani, R., & Karthik, B. (2023). Analysis of grass diversity of Nilgiri Biosphere Reserve, India, with special emphasis to the endemic species. *Nelumbo*. <https://doi.org/10.20324/nelumbo/v65/2023/172942>
- Jain, S. K. (2024). The Grass Flora of India - A Synoptic Account of Uses and Phytogeography. *Nelumbo*, 229–240. <https://doi.org/10.20324/nelumbo/v28/1986/74877>
- Paul, S., Saha, S., Nigam, P., Ali, S. Z., Page, N., Khan, A. S., Kumar, M., Habib, B., Mohan, D., Pandav, B., & Mondol, S. (2023). Spatiotemporal evaluation of waning grassland habitats for swamp deer conservation across the human-dominated upper Gangetic Plains, India. *Environmental Conservation*, 50(3), 169–178. <https://doi.org/10.1017/s0376892923000140>

RAPID GROWTH OF WATER HYACINTH IN WETLANDS:

A BLESSING OR A CURSE?

Dr. Soumita Mitra, Research Scholar

Institute of Environmental Studies and Wetland Management (IESWM)

Introduction:

Water hyacinth (*Eichhornia crassipes*) is a free-floating aquatic plant known for its attractive purple flowers and rapid growth. It originated in South America's Amazon Basin and has since spread to many other countries, including India. Because of its conflicting effects on ecosystems, economies, and human existence, it is frequently discussed as both a blessing and a curse, despite the fact that it may seem lovely and even beneficial in some situations. The current report will attempt to offer all sides of the issue.

Botanical characteristics of the species:

The widespread species belongs to the Family Pontederiaceae. The plant not only shows beautiful purple flowers but also has thick, waxy, oval-shaped leaves and long, fibrous roots. These special adaptive features help the plant reduce transpiration from its leaves, retain moisture, and float and spread on the surface of the water in its habitat. The waxy coat can even help the plant prevent waterlogging, allowing it to float on water.

The optimal temperature and nutrient levels have made this species invasive, and under nutrient-rich conditions, the growth rate can reach 10kg/m² in around 50 days (Harun et al., 2021).



Figure 1: picture of the invasive species

Negative impact of the plant species:

People are very much aware of the negative impact of water hyacinth on the wetland ecosystem; specifically, local inhabitants are more inclined to notice the direct impact of the species. This piece of writing will point out some of the advanced negative impacts of these notorious macrophytes, which are as follows (Figure 2):

- **Ecological impact:** Under suitable conditions of temperature and available nutrients, the species has a rapid growth rate of nearly 0.1 Kg/m² (approx.), forming dense floating mats on the surface of water bodies. This blocks sunlight from reaching submerged plants and inhibits photosynthesis, leading to their death. As these plants decay, the decomposition process consumes dissolved oxygen, creating hypoxic conditions that can kill fish and other aquatic organisms.

The thick vegetation also restricts the movement, feeding, and breeding of aquatic species, thereby disrupting natural habitats and food chains. Additionally, water hyacinth outcompetes native species for nutrients and space due to its fast growth rate, resulting in monoculture dominance (Shen et al., 2025). This combination of light obstruction, oxygen depletion, habitat alteration, and competitive exclusion ultimately leads to a significant decline in both plant and animal diversity within the ecosystem.

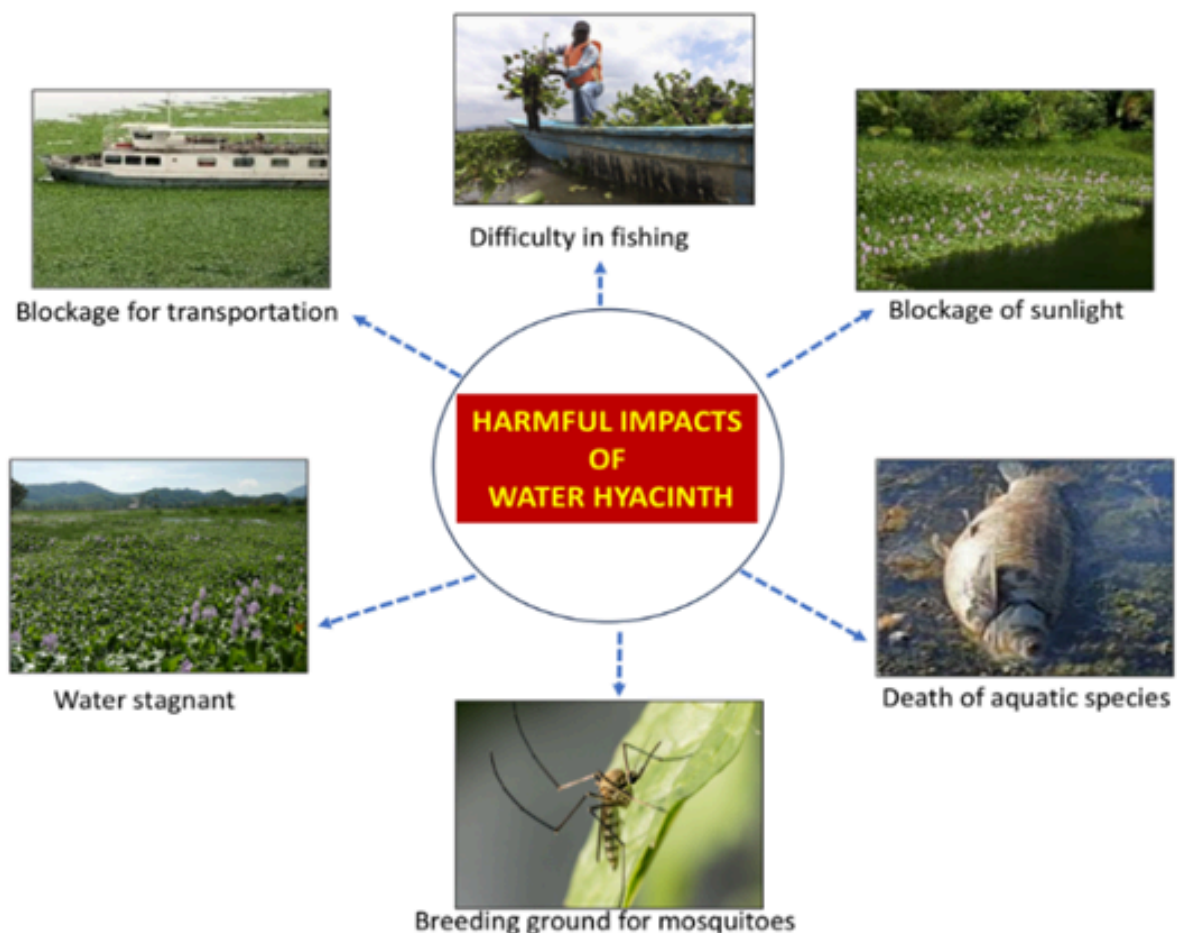


Figure 2: The schematic diagram of the negative impact of the studied species

- **Economic Impact:** The detrimental impact has also been proved to disrupt several economic sectors. Its quick growth creates thick mats that jam lakes, rivers, and irrigation canals, raising the expense of upkeep and removal for local and federal governmental entities. Because of habitat loss and oxygen depletion, fish populations decline, leading to lower catches and reduced earnings for fishermen (Getahun & Kefale, 2023). Additionally, it hinders transportation and navigation routes, impacting local lives and trade while increasing journey times and fuel expenses. Blocked irrigation systems in agriculture restrict water delivery, which lowers output; reports also state that output can decrease by up to 45–90% (Getahun & Kefale, 2023). Additionally, by diminishing the aesthetic and ecological value of water bodies, water hyacinth infestations can have a detrimental effect on recreational and tourist activities. It is a significant financial burden, particularly in developing nations, due to the total cost of control measures as well as losses in transportation, tourism, agriculture, and fisheries.

- **Direct Environmental Impact:** By changing the normal flow and equilibrium of water bodies, water hyacinth damages the ecosystem in a number of ways. Because of its dense matting, water moves more slowly and becomes stagnant, which encourages the growth of dangerous microbes and results in poor water quality. Particularly in areas that are currently under water stress, the greater leaf surface area exposed to sunlight causes significant evaporation losses, which lowers total water availability. Furthermore, the dense growth may obstruct streams and drainage systems, limiting regular water movement and increasing the risk of floods during periods of high precipitation (Nega et al., 2022).
- **Health hazards:** This invasive aquatic plant creates dense mats (around 2 m in depth) that slow down water movement and create stagnant conditions, which are ideal for mosquito larvae to develop and proliferate (Bickel, 2025). As a result, populations of mosquitoes significantly increase, which directly aids in the spread of vector-borne illnesses like dengue and malaria. These illnesses pose a serious risk to human health and increase the strain on healthcare systems.



Positive impact of the plant species:

Researchers from several nations have recently become aware of the species' effects. To their astonishment, they have discovered that this species not only has detrimental effects on the environment and ecosystem but also has some beneficial effects through which management could be achieved. Water hyacinth is also a blessing to the environment and to local inhabitants. There are many ways in which the species has shown beneficial impacts (Figure 3), which will be discussed in this report.

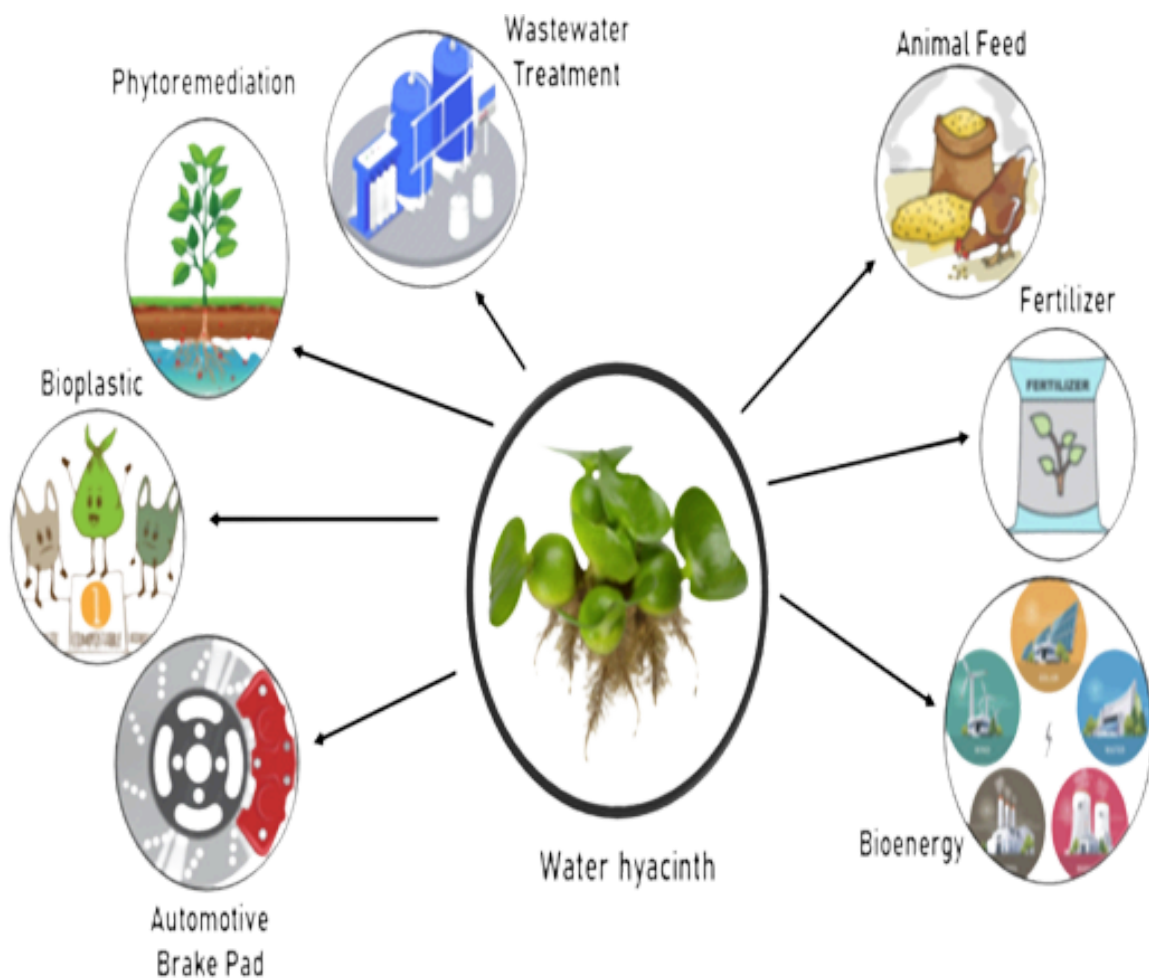


Figure 3: Schematic diagram of the possible positive implications of water hyacinth species

- **Environmental benefits:** The most significant environmental advantage is water filtration. This plant is remarkably capable of absorbing and accumulating hazardous heavy metals from polluted water bodies, including lead, mercury, and arsenic. It aids in the treatment of wastewater by eliminating excess nutrients, organic materials, and dangerous pollutants through a natural process called phytoremediation.

Further, by capturing suspended particles and enhancing the general quality of the water, its vast root system functions as a biological filter. Thus, it contributes to the reduction of water pollution and may be utilized for environmentally friendly wastewater management under regulated settings.

- **Economic benefits:** Because of its fibrous nature, it is a good raw material for making eco-friendly handicrafts that are becoming more and more popular in sustainable marketplaces, such as bags, mats, sarees, and baskets. The plant may also be used to make paper and natural fibers, which lessen reliance on traditional raw resources like wood. Particularly in rural locations, these activities give local populations the chance to harvest, process, and market goods made from water hyacinth (Kumari et al., 2026). As a result, it encourages sustainable rural development and generates income in addition to aiding in the management of the invasive species.
- **Agricultural and energy production:** It also has valuable applications in agriculture and energy production when managed properly. It can be converted into compost and organic manure, enriching soil fertility by adding essential nutrients and improving soil structure. The plant is also widely used in biogas production, where its high organic content is broken down anaerobically to generate renewable energy in the form of methane-rich gas.
- **Animal feed:** After proper drying and treatment to remove toxins, water hyacinth can be used as supplementary animal feed for livestock. These uses not only help in controlling its excessive growth but also promote sustainable farming practices and alternative energy generation (Wang, 2022).

Conclusion:

Thus, the report provides both the positive and negative impacts of water hyacinth on the ecosystem and human population. On the one hand, it creates health risks, including the spread of dengue and malaria, disrupts aquatic habitats, decreases biodiversity, and obstructs rivers. However, it has several advantages, such as resource recovery, water cleansing through phytoremediation, and the creation of livelihoods through composting, handicrafts, and bioenergy production. So, it is very difficult to consider water hyacinth strictly a blessing or a curse. But if this species is maintained responsibly and with utmost care, it may be turned from an environmental burden into a useful natural asset that promotes ecological balance and socioeconomic development through right management strategies and creative applications.

Reference:

- Bickel, T. O. (2025). Aquatic Plant Management. In *Recent Advances in Weed Science* (pp. 189-215). Cham: Springer Nature Switzerland.
- Getahun, S., & Kefale, H. (2023). Problem of water hyacinth (*Eichhornia crassipes* (Mart.)) in Lake Tana (Ethiopia): ecological, economic, and social implications and management options. *International Journal of Ecology*, 2023(1), 4618069.
- Harun, I., Pushiri, H., Amirul-Aiman, A. J., & Zulkeflee, Z. (2021). Invasive water hyacinth: Ecology, impacts and prospects for the rural economy. *Plants*, 10(8), 1613.
- Kumari, R., Boerma, B., Ahmed, R., Suman, S., Sharma, S., & Dhawan, S. (2026). Assessing economic and livelihood impacts of water hyacinth utilisation in rural India: A mixed-methods study. *Dynamics of Rural Society Journal*, 4(1), 60-69.

Vox Populi



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BIODIVERSITY AND ECOSYSTEM RESTORATION FOR SUSTAINABLE FUTURES

Ms. Anjana Bhattacharya, Senior Business Analyst, IDBI Bank Ltd.

Introduction

Nature is under increasing pressure, yet it retains a remarkable capacity to recover. Biodiversity loss now threatens ecosystems and human well-being across the globe. Ecosystem restoration offers a practical and urgent pathway toward sustainability and resilience.

Biodiversity refers to the variety of life, including plants, animals, and microorganisms, as well as the ecosystems they form. Healthy ecosystems provide essential services such as clean water, fertile soils, and climate regulation. However, unsustainable land use, deforestation, and pollution have significantly degraded these systems. According to the United Nations Environment Programme (2020), ecosystem degradation directly affects livelihoods and food security worldwide.

Community Voices: A Kenya Case Study

In Machakos County, Kenya, local communities have demonstrated how restoration can reverse environmental decline. Historically affected by soil erosion and low agricultural productivity, the region has seen significant improvement through terracing, agroforestry, and water conservation practices.

These approaches reduce runoff, improve soil structure, and enhance crop yields. Farmers have reported noticeable changes, including increased vegetation cover and more reliable harvests. The integration of indigenous tree species has further strengthened biodiversity and improved resilience to climate variability. Support from institutions such as the Kenya Forest Service has reinforced these efforts through training and policy support.

As shown in Figure 2, these restoration practices have significantly improved land productivity and resilience.

Environmental Impact

Ecosystem restoration generates multiple environmental benefits. Reforestation enhances carbon sequestration, helping mitigate climate change, while restored wetlands improve water quality and reduce flood risks. Healthy soils support agricultural productivity and biodiversity recovery. According to the Food and Agriculture Organization (2021), restored ecosystems can recover a significant portion of their biodiversity over time.

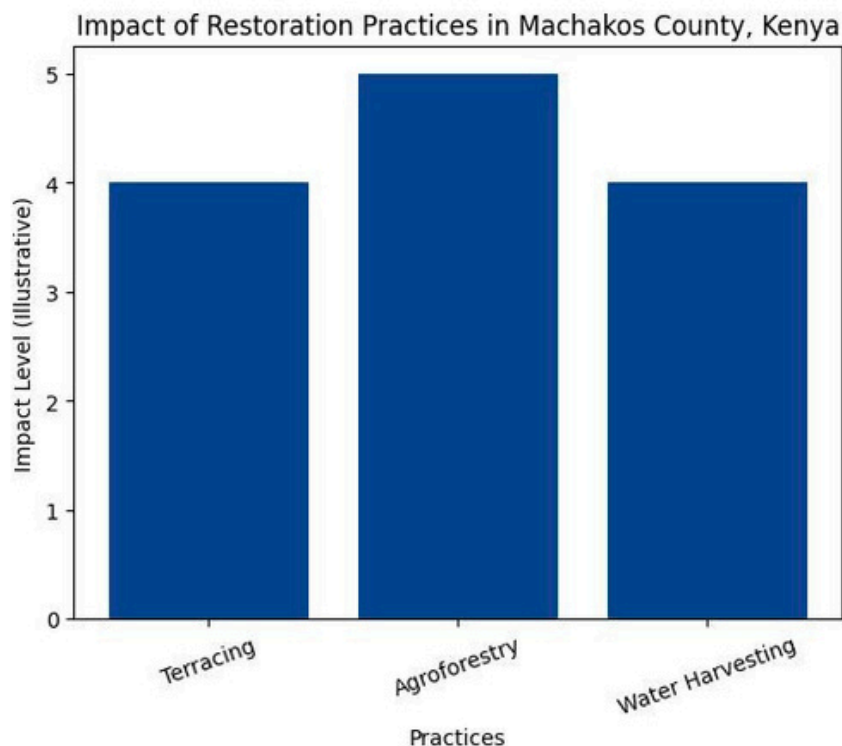


Figure 2. Impact of restoration practices in Machakos County, Kenya. The chart illustrates how terracing, agroforestry, and water harvesting contribute to improved soil fertility, reduced erosion, and increased agricultural productivity.
Source: Adapted from FAO (2021) and community restoration initiatives.

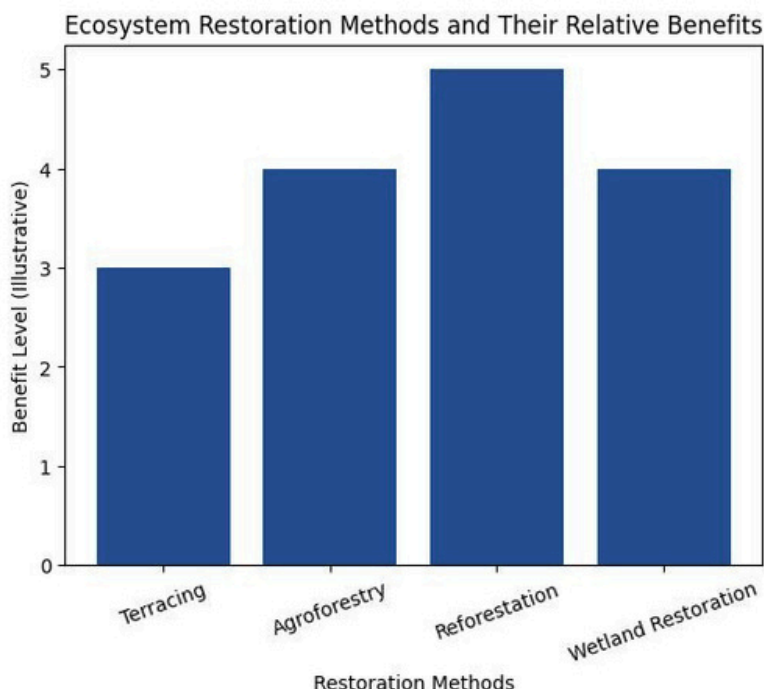


Figure 1. Ecosystem restoration methods and their relative environmental benefits. The chart illustrates the contribution of terracing, agroforestry, reforestation, and wetland restoration to ecosystem recovery.
Source: Adapted from FAO (2021).

Table 1. Common ecosystem restoration methods and their environmental benefits

Restoration Method	Key Benefits
Terracing	Reduces soil erosion and improves water retention
Agroforestry	Enhances soil fertility and supports biodiversity
Reforestation	Increases carbon storage and restores habitats
Wetland Restoration	Improves water quality and controls flooding

Source: FAO (2021)

Lessons Learned and Policy Reflections

Effective restoration depends on community participation, the use of native species, and long-term commitment. Local knowledge plays a crucial role in designing practical solutions. Global initiatives such as the United Nations Decade on Ecosystem Restoration (2021–2030) emphasise the importance of coordinated action. Policies that promote sustainable land use and provide incentives for conservation can significantly scale up restoration efforts.

Conclusion

Ecosystem restoration is essential for rebuilding biodiversity and supporting human well-being. The experience of Machakos County demonstrates that local action can produce meaningful environmental and economic benefits. By combining scientific knowledge, community engagement, and supportive policies, societies can restore ecosystems and secure a sustainable future.

References

- Food and Agriculture Organization. (2021). *The State of the World's Forests 2021*.
- United Nations Environment Programme. (2020). Ecosystem restoration for people, nature and climate.

ECOSYSTEM SERVICES IN TRANSITIONAL WETLANDS AND GRASSLANDS:

SAFETY NET OF NATURE

Ms. Annyesha Purkait, Young Professional, National Institute of Disaster Management (NIDM), MHA, GoI

People in many parts of South Asia receive 'ecosystem services' daily, even if they do not often discuss them. They receive the ecosystem services through receding floodwaters, fertile soils that support crops, and grazing lands that serve livestock. Often, with clear consequences, the invisible activities are gradually disappearing as wetlands and grasslands undergo rapid changes.

Setting the Context: Transition in Landscapes

Apart from changes in physical terms, ecosystems in transition are also experiencing shifts in the process of providing and functioning, leading to reorientation of ecosystem services. This results in compromising long-term sustainability in expense of strengthening short-term benefits (De Groot et al., 2010). Saying that, we can look into an example where the conversion of wetlands into agricultural land leads to efficient productivity, but it gradually decreases the water regulation and biodiversity support. In our world, the most active ecosystems to be found are wetlands and grasslands, constantly shaped by the cycle of seasons, hydrology, and human consumption. In recent times, however, the rate and scale of change have become faster.

Expansion in urbanization, intensive agriculture, and variations in climate have modified the composition and functioning of South-Asian ecosystems (Millennium Ecosystem Assessment [MEA], 2005).



Source: Dialogue Earth

Figure 1. Drying up of the Brahmaputra wetlands in Assam

Beyond Theory: Comprehending Ecosystem Services

One of the leading global assessments, such as MEA, gave prominence to the concept of ecosystem services, which classified these services into equipping, controlling, cultural, and supporting categories. While the classification is logically useful, these services are highly interconnected on the ground.

For instance, fisheries (an equipping service) in a wetland system depend on the quality of water (a controlling service), which in turn leans on nutrient cycling (a supporting service). Similarly, rather than existing independently of ecological processes, cultural services like spiritual and recreational values are usually embedded in them (Costanza et al., 1997).

In transitional ecosystems, especially where variations in one component can generate cascading effects across the systems, identifying these interconnections becomes equally essential.

Wetlands as Life Support Systems and Risk Buffers

Wetlands are frequently referred to as ‘natural sponges’, although this metaphor only partially explains their function. They manage the flow of water, eliminate pollutants, revive groundwater, and enhance biodiversity. By absorbing the excess amount of rainfall and releasing it slowly in flood-prone areas, high flood levels are lessened in wetlands (Barbier et al., 2011). For example, in eastern India, wetland systems have widely supported livelihoods through fisheries and agriculture while simultaneously acting as barriers against flooding.

However, with the change in time, many wetlands have been filled in or encroached upon with the expansion of urban areas. According to various studies, there is a direct correlation between the loss of wetlands and a rise in flood occurrences, drenching the urban areas (MEA, 2005). From the viewpoint of disaster management, wetlands provide a cost-effective and sustainable form of protection.



Source: India Water Portal

Figure 2. Fisherwomen in the Tinsukia District of Assam, where wetlands act as a source of livelihood support for rural households

Rather than built infrastructure, they respond to shifting environmental conditions and generate various mutual benefits, leading to wide acknowledgement of wetlands as nature-based solutions for climate adaptation and disaster risk reduction (Renaud et al., 2013).

Grasslands: The Ignored Ecosystems

Frequently labelled as ‘wastelands’, grasslands, in contrast, are often overlooked and suffer from a lack of recognition in discourse about conservation and policy. Wetlands are among some of the world’s endangered ecosystems (White et al., 2000). Yet, grasslands are vital for the livelihood security of pastoral communities. In these ecosystems, numerous plant and animal species can be found that also support cattle grazing and increase soil fertility. In semi-arid regions where agriculture may fail due to climatic variability, grasslands are

particularly important as they can sustain production under these conditions (Sala & Paruelo, 1997).

However, there is a rapid conversion of grasslands into agricultural land or industrial zones. As a result of this shift, ecological processes are interrupted, and their ability to offer ecosystem services is decreased. Degradation is further aggravated due to overgrazing, the spread of invading species, and disruptions in land tenure systems (MEA, 2005).

When Ecosystems Change, Services Fall

The fact that degradation is commonly slow in nature and is not immediately visible is one of the important perceptions from ecosystem services research. Although existing physically, a wetland may no longer be able to regulate floods or sustain biodiversity.



Figure 3. The spread of invasive plant species like Chromolaena and Parthenium in the grasslands of Manas and Pobitora National Parks, respectively, is replacing native species and altering the dynamics of the ecosystem

Likewise, grasslands may continue to be vegetated, yet they will experience a drop in the diversity and productivity of species. When ecosystems reach the threshold, beyond which recovery faces difficulty, such changes are often referred to as “threshold effects” (Costanza et al., 1997). Instead of a single event, cumulative stresses in transitional ecosystems may cause these thresholds to be exceeded. Human well-being is directly affected by the decay in ecosystem services. Both urban and rural communities are affected due to depleted water quality, increased risks of flooding, and deteriorating agricultural productivity. Most commonly, the more vulnerable groups are the first ones to experience these impacts.

Daily Adaptation and Shared Knowledge

Through traditional customs, local communities have largely adapted to the dynamics of wetlands and grasslands. Through traditional customs, local communities have largely adapted to the dynamics of wetlands and grasslands.

The reflection of a thorough understanding of ecosystem processes is demonstrated through water harvesting techniques, seasonal fishing, and rotational grazing. These practices tend to be adaptable and responsive to changes in the surrounding environment.

Formal policy networks, however, rarely acknowledge or incorporate this knowledge into account. Without considering the current ecological linkages, the focus of development interventions might be on infrastructure or economic outputs. Unexpected consequences like resource conflicts and ecosystem degradation may result from this. The probability of community-based initiatives to strengthen ecosystem management is getting wide recognition. These strategies can integrate conservation objectives with livelihood requirements by considering the involvement of local stakeholders (Bennett et al., 2017). A sense of ownership and accountability for natural resources is also promoted with their aid.



Source: Vikalp Sangam

Figure 4. A drone shot of observing World Wetlands Day at Langolsabi locality of Champu Khangpok floating village

Policy Reconsideration: From Protection to Integration

Although policy integration of ecosystem services is still unequal, they are getting due recognition in international frameworks. By focusing on short-term impacts, environmental impact assessments often ignore long-term ecosystem service losses. The interconnectedness of ecosystems is recognized by implementing integrated frameworks, which are required to go beyond sectoral approaches. For instance, urban planning and disaster management should be linked with wetland conservation. Likewise, rural development and livestock policies should be integrated with grassland management. If ecosystem service assessment is integrated into planning procedures, then it helps the connection to be more apparent. Despite its limitations, this assessment provides a means of communication to convey the significance of the ecosystem in economic and policy terms (De Groot et al, 2010).

Conclusion

More than just mere ecological spaces, wetlands and grasslands are a part of the ecosystem that promotes life, livelihood, and resilience. The services of these ecosystems that are continuously transitioning are becoming more vulnerable. Informed decision-making and sustainable development rely on acknowledging and valuing these services. In several ways, ecosystem services, although frequently going unnoticed, quietly support human societies by representing themselves as the safety net of nature. Protecting this safety net is our responsibility. For this, a shift in our perception of the ecosystem and engagement with it is required, along with conservation efforts. Thus, resilience in a changing world will depend both on ecological health and human creativity.

References

- Barbier, E.B., Hacker, S.D., Kennedy, C., Koch, E.W., Stier, A.C., & Silliman, B.R. (2011). The value of estuarine and coastal ecosystem services. *Ecological Monographs*, 81(2), 169-193.
- Bennett, N. J., Roth, R., Klain, S. C., Chan, K., Christie, P., Clark, D. A.,... & Wyborn, C. (2017). Conservation social science: Understanding and integrating human dimensions to improve conservation. *Biological Conservation*, 205, 93-108.
- Costanza, R., d'Arge, R., De Groot, R., Farber, S., Grasso, M., Hannon, B.,... & Van Den Belt, M. (1997). The value of the world's ecosystem services and natural capital. *Nature*, 387(6630), 253-260.
- De Groot, R. S., Alkemade, R., Braat, L., Hein, L., & Willemen, L. (2010). Challenges in integrating the concept of ecosystem services and values in landscape planning, management and decision making. *Ecological Complexity*, 7(3), 260-272.
- Millenium Ecosystem Assessment (MEA). (2005). *Ecosystems and human well-being: Synthesis*. Island Press.
- Renaud, F. G., Sudmeier-Rieux, K., & Estrella, M. (Eds.). (2013). *The role of ecosystems in disaster risk reduction*. United Nations University Press.
- Sala, O. E., & Paruelo, J. M. (1997). Ecosystem services in grasslands.
- White, R., Murray, S. & Rohweder, M. (2000). *Pilot analysis of global ecosystems: Grassland ecosystems*. World Resources Institute.

HABITAT AND NICHE TRANSITIONS IN THE BANNI GRASSLANDS:

A SOCIO-ECOLOGICAL LANDSCAPE ASSESSMENT

Ms. Anolita Singho, Communication Officer (PFRI)

Abstract

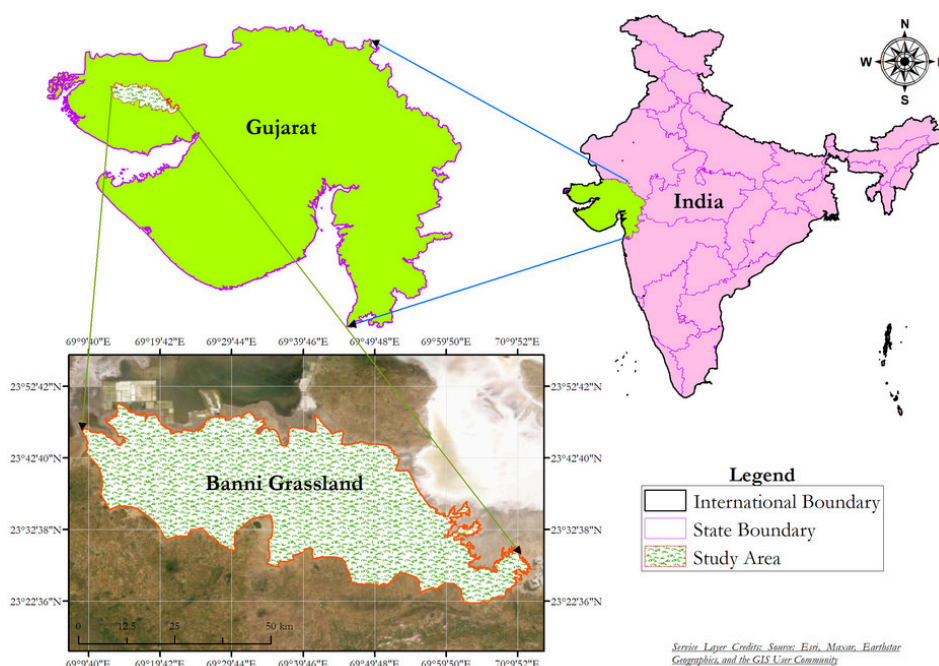
Grassland ecosystems in India are undergoing rapid ecological and socio-economic transitions, often driven by invasive species, climatic variability, and changing governance frameworks. The Banni grasslands of Gujarat represent a critical case where habitat transformation intersects with pastoral livelihoods. This paper examines the transition of habitat structure and ecological niches through a landscape lens, while foregrounding the lived experiences of the Maldhari pastoral communities. It argues that ecological change in Banni cannot be understood in isolation from community dynamics, and that sustainable conservation must integrate local knowledge systems with adaptive management approaches.

Introduction

Grasslands have historically been undervalued within conservation discourse in India, frequently categorized as “wastelands” despite their ecological and socio-economic significance. The Banni Grasslands, situated along the periphery of the Great Rann of Kutch, constitute one of the largest contiguous grassland systems in the country.

Traditionally, Banni has supported a mosaic of native grasses, seasonal wetlands, and grazing regimes maintained by Maldhari pastoralists. However, over recent decades, the region has undergone significant transformation. These changes are reflected not only in vegetation structure but also in the reconfiguration of ecological niches and livelihood strategies. This study adopts a

landscape assessment perspective to analyze these transitions, with particular emphasis on how they are perceived and experienced by local communities.



Service Layer Credits: Source: Esri, Mapbox, Earthstar
Geographics, and the GIS User Community

Ecological Context and Habitat Structure

The ecological character of Banni is shaped by a combination of edaphic factors, salinity gradients, and seasonal hydrological cycles. Native grass species such as *Cenchrus* spp. and *Dichanthium* spp. historically dominated the landscape, supporting a range of herbivores, avifauna, and soil biota. From a habitat perspective, the system functioned as an open grassland with spatial heterogeneity. This heterogeneity was critical in maintaining ecological niches:

- Short-grass patches supported grazing herbivores
- Taller grasses facilitated nesting by ground-dwelling birds
- Moist depressions enabled seasonal productivity

Pastoral grazing, when practiced under traditional regimes, contributed to maintaining this structural diversity.

Landscape Transition and Ecological Curiosity

Recent decades have witnessed a marked shift in vegetation composition, primarily associated with the proliferation of *Prosopis juliflora*. Initially introduced for land stabilization and resource provision, the species has expanded across large parts of Banni. From a landscape assessment standpoint, this transition is characterized by:

- Conversion of open grasslands into woody thickets

- Reduction in native grass cover
- Alteration of soil moisture and salinity dynamics

These changes have significant implications for ecological niches. Species adapted to open habitats face habitat contraction, while newly formed niches within dense vegetation remain limited in supporting comparable biodiversity.

For researchers, Banni represents a site of ecological inquiry raising questions about resilience, thresholds of invasion, and the long-term stability of transformed ecosystems.

Community Perspectives on Ecological Change

For the Maldhari communities, ecological transition is not an abstract concept but a lived reality. Their knowledge systems, built on generational observation, provide critical insights into landscape change.

Community narratives consistently highlight:

- A decline in palatable grass species
- Increased difficulty in accessing grazing areas
- Changes in seasonal patterns affecting fodder availability

Unlike scientific assessments that quantify land-use change, Maldhari observations emphasize functional shifts, how the land 'behaves' in terms of productivity, accessibility, and reliability.

Importantly, while *Prosopis juliflora* is often identified as a driver of ecological change, community perspectives are nuanced. The species is simultaneously viewed as:

- A constraint (reducing grazing land)
- A resource (providing fuelwood and supplementary income)

This duality underscores the complexity of ecosystem transitions when viewed through a livelihood lens.



Conflict Across Scales

The transition of Banni is marked by overlapping conflicts that operate at ecological, economic, and institutional levels.

Ecological Conflict

The dominance of *Prosopis juliflora* has disrupted native ecosystem processes, leading to reduced grassland functionality and altered habitat conditions.

Livelihood Conflict

Pastoral systems are increasingly under stress due to:

- Reduced fodder availability
- Increased dependence on external inputs
- Shifts in livestock composition and mobility

These changes challenge the sustainability of traditional grazing systems.

Governance Conflict

Banni's status as a common property landscape, coupled with ambiguous land classification, has resulted in limited clarity in management regimes. Community members often report:

- Restricted participation in decision-making
- Limited recognition of traditional practices
- Uncertainty regarding land rights and access

Such institutional gaps contribute to a disconnect between conservation objectives and local realities.

Conservation in a Transitioning Landscape

Conservation in Banni requires moving beyond static notions of ecosystem restoration toward adaptive and context-specific strategies.

Landscape-Based Approaches

Effective interventions must consider spatial variability and prioritize:

- Selective management of invasive species
- Restoration of native grasses in suitable zones
- Maintenance of habitat mosaics

Integrating Community Knowledge

Maldhari pastoralists possess detailed understanding of grazing cycles, plant species, and seasonal dynamics. Incorporating this knowledge can enhance the effectiveness and acceptability of conservation strategies.

Reframing Policy Perspectives

Recognizing grasslands as ecologically significant systems is essential. Policy frameworks must shift from viewing such landscapes as degraded to acknowledging their role in supporting biodiversity and livelihoods.

Conclusion

The Banni grasslands exemplify an ecosystem in transition, where habitat transformation and niche reconfiguration are closely intertwined with human experience. From the perspective of local communities, these changes are not only ecological but deeply socio-economic.

A landscape assessment that integrates scientific analysis with community knowledge reveals that conservation cannot be pursued in isolation. Instead, it must address the dynamic relationship between ecosystems and the people who depend on them. In Banni, the path forward lies in balancing ecological restoration with livelihood resilience ensuring that conservation strategies are not only scientifically sound but also socially grounded.

References

- ATREE. (2012). *Ecology and management of Banni Grassland of Kachchh, Gujarat*. Ashoka Trust for Research in Ecology and the Environment. <https://archived.atree.org/journal-articles/ecology-and-management-banni-grassland-kachchh-gujarat>
- Daghamo, J. P., Patel, H., & Ram, H. (2024). Invasive networks: An environmental history of the introduction of *Prosopis juliflora* to Banni grassland, India. *Geoforum*, 158, Article 103664. <https://doi.org/10.1016/j.geoforum.2024.103664>
- Jany, R., Gupta, D. C., & Datt, R. (2019). Occupational structure and determinants of household income of pastoralists in Banni grasslands of Gujarat. *Indian Journal of Animal Sciences*, 89(4), 449–456. <https://epubs.icar.org.in/index.php/IJAnS/article/view/89149>
- Kumar, S., Jany, R., & Gupta, D. C. (2021). Ecological, economic and socio-cultural sustainability of different livelihood options and enterprises practised by pastoralists in Banni grasslands of Gujarat. *Indian Journal of Animal Sciences*, 91(8), 1143–1152. <https://epubs.icar.org.in/index.php/IJAnS/article/view/114339>
- Naithani, A., Jathar, S., & Mathur, V. B. (2024). Maximising ecological value and assessing land suitability for sustainable grassland management in Asia's largest tropical grassland, Western India. *PLOS ONE*, 19(6), Article e0305053. <https://doi.org/10.1371/journal.pone.0305053>
- Pattanaik, C., Prasad, S. N., & Dash, P. K. (2009). Local perceptions of grassland change and priorities for conservation of natural resources of Banni, Gujarat, India. *Tropical Ecology*, 50(2), 269–282. <https://doi.org/10.1007/s11515-009-0041-6>
- Government of Gujarat, Forest & Wildlife Department. (2015). *Banni Grassland Management Plan*.
- Sahapedia. (2014). *Maldharis, the silvipastoralists of the Banni Grasslands*. <http://www.sahapedia.org/maldharis-the-silvipastoralists-of-the-banni-grasslands>
- Wikipedia contributors. (2026). *Banni Grasslands Reserve*. Wikipedia. https://en.wikipedia.org/wiki/Banni_Grasslands_Reserve

WHOSE WETLAND IS IT?

VOICES FROM THE EDGE OF SHRINKING WETLANDS

Dr. Bhaskar Deb Bhattacharya, Senior Research Officer (PFRI)

Dawn breaks slowly over Loktak Lake. Ramdas pushes his old canoe through the floating islands called phumdis. These floating mats of reeds, grasses, and peat drift across the lake like green islands. His rough hands repair a torn fishing net. Morning fog settles on his worn lungi. He moves quietly through the shallow water, searching for fish. For families like his, the phumdis are life itself. They support fish, birds, and people who have depended on the lake for generations. But every year, the paths between the floating islands grow narrower. His nets bring back fewer fish. "In my father's time, the lake was full of singhara and rohu," Ramdas says. "One throw of the net fed the whole family. Now the water is shrinking. Fish are disappearing. Our world is changing." His voice carries worry. The lake that raised him now feels uncertain.

Located in Manipur, Loktak Lake is the largest freshwater lake in Northeast India. It supports the lives of thousands of people. Its most special feature is the phumdis. These floating islands are made of plants, roots, and soil. They drift slowly across the water. The lake provides many benefits. It supports fisheries that feed families. It offers land for small farming and gathering plants. It holds rich biodiversity, including birds and fish. It also provides drinking water. Nearby lies Keibul Lamjao National Park, the world's only floating national park.

It is the last home of the endangered Sangai deer. This ecosystem is rich. But today, pollution, encroachment, and climate change threaten its future.

Fishing in Loktak is more than work. It is a tradition passed from one generation to the next. Families like the Kshetrimayums have fished here for decades. Their lives follow the rhythm of the lake. But things have changed. Fish catches have dropped sharply over the past twenty years. "My grandfather caught 20 to 30 kilograms a day," says Thoi Singh, a 52-year-old fisherman. "Now I struggle to catch five." Space is also shrinking. Artificial fish pens called athaphums have spread across the lake. These circular bamboo structures are used for fish farming. "They block our paths," says Leishangthem Rani, a widow raising three children. "They trap the fish we depend on." Costs are rising. Fuel and fishing gear are expensive. Income is falling. Many families struggle to survive. The question grows louder: Who owns the lake? Traditional fishers or modern fish farms?

Along the edges of the lake, farmers are expanding their fields. Wetland areas are slowly being turned into farmland. This change affects the flow of water into the lake. Areas that once filled during the monsoon now dry up quickly. Chemicals from farming also enter the water. Fertilizers and pesticides wash into the lake. The water becomes cloudy and polluted.

"Our fields need water," says farmer Ngangom Ibohal. "But sometimes we harm the lake without meaning to." Rice production has increased. But the health of the lake has declined. Fishers complain that fish breeding grounds are disappearing. Farmers say they must grow food to survive. This creates tension. Land gained from water today may lead to loss tomorrow. To protect the lake, the government introduced laws such as the Loktak Lake Protection Act of 2006. Authorities have removed many athaphums. Floating settlements have also been cleared in some areas. Officials say these actions are necessary. They believe restoring native plants and reducing pollution will improve fish stocks. But these measures also affect livelihoods. "Policies may save the lake in the future," says Momon Devi, an evicted fisher. "But today, we struggle to feed our families." Many people feel excluded from decisions. They want solutions that involve local communities. Trust between people and authorities remains fragile.

The lake itself shows signs of distress. Water levels have reduced over the years. Silt fills the channels. The water looks muddy and thick. Invasive plants like water hyacinth spread rapidly. They block sunlight and reduce oxygen in the water. Many fish species have declined. Birds that once filled the sky are seen less often. Some areas have become silent. Nets return empty. Boats drift without purpose. The ecosystem is weakening. And with it, people's lives grow more uncertain.

Despite these challenges, communities continue to adapt. Many young people leave fishing behind. They move to cities like Imphal in search of work. "My sons work with computers," says Yumnam. "They do not fish as we did." Women are finding new ways to earn income.

Some make handicrafts from lotus stems. Others join eco-tourism activities. Still, conflicts remain. Fishers argue over space. Athaphum operators defend their livelihoods. In some places, cooperation is growing. Fisheries groups are forming committees to protect fish stocks and manage resources. Adaptation brings both hope and struggle.

The lake connects many lives. Fishers depend on its waters. Farmers depend on its soil. Policymakers depend on its protection. Each group claims a stake. Traditional communities speak of ancestral rights. Authorities speak of conservation laws. Private fish farms raise questions. Are they innovation or enclosure? The wetland is not just a resource. It is a shared responsibility. Ownership should not mean control. It should mean care. As the sun sets over Loktak Lake, a young boy throws a fishing net beside his grandfather. The phumdis glow golden in the evening light. In the distance, the Sangai deer moves quietly across the floating grasslands of Keibul Lamjao National Park. There is still hope. Solutions that combine traditional knowledge with science could protect both people and nature. But without careful action, the lake may fade into memory. The question remains - Whose wetland will it be tomorrow? Ours to protect-or ours to lose?



Source: Communication Department, PERI

GRASSLANDS AT THE MANGROVE FRINGE:

A STORY OF CHANGE AND ADAPTATION IN THE SUNDARBAN

Mr. Sujay Bhattacharjee, Research Assistant (PFRI)

In the Indian Sundarban, grass-dominated habitats are transitional landscapes that are not always adequately valued, but still remain ecologically important. Different grass communities occur along a gradient from swampy intertidal mangroves and salt marshes to drier non-mangrove areas. Over time, these landscapes reflect shifts in the deltaic environment and changing relations between mangrove, non-mangrove, and marshy conditions. For people living in the Sundarban, however, these landscapes are not only ecological zones. They are lived spaces, shaped by work, uncertainty, and adaptation.

Badal Mondal, a resident of Kultali village in the Sundarban, comes from a family that has farmed for generations in the mangrove fringe, where soil, water, and survival are never stable, only negotiated. In recent years, however, the tides have changed in ways that even older generations did not foresee. Cyclones have become harsher, embankments weaker, and the rivers, once more familiar in their behaviour, have grown increasingly erratic. After the last major flood, saline water enters his fields and leaves behind a hardened crust. What was once fertile paddy land now becomes a transitional grassland, a space in between, neither fully lost nor truly restored.

To Badal, it feels like losing the land he once knew. Yet the land does not remain barren. Slowly, life returns, though not in the old form. Salt-tolerant grasses begin to spread across the silted fields, their roots holding the soil where crops have failed. Patches of wildflowers emerge, scattered but persistent, drawing bees and butterflies. In low-lying depressions, rainwater mixes with tidal seepage to form shallow seasonal wetlands.

One morning, while walking along the edge of his former field, Badal notices white egrets stepping lightly through the water and probing the mud for food. Later, he sees children moving through the tall grasses, their laughter replacing the silence of abandoned cultivation. An elderly woman from the village bends to collect medicinal herbs that have not grown there in years. Then deer begin to appear, hesitant at first and then more at ease, moving through the grassland as though reclaiming something long absent. Badal gradually understands that this is not wasteland. It is a changing landscape.

Drawing on what he has learned from elders and from his own observations, he begins to adapt. Instead of forcing the land back into paddy, he experiments with salt-tolerant and drought-resistant crops on small raised plots.

He allows parts of the grassland to remain undisturbed and notices that they protect the soil from erosion. He works with local beekeepers, recognizing that the flowering grasses and wild plants provide a useful nectar source. Even the cut grasses find value, as mulch, as fodder, and as a means of rebuilding organic matter in tired soils.

The returns are modest, but meaningful. The millet he grows is coarse yet nourishing. The honey, drawn from wild blooms, carries a distinct flavour. The land, though altered, does not stop giving; it simply changes in character.

For Badal, the grassland at the mangrove fringe becomes more than a temporary phase. It becomes a lesson in how to live with change. It teaches him to pay attention again to tides, to soil, and to the quiet signs of recovery. Farming is no longer only about restoring the past, but about adjusting to the present. In the shifting space between mangrove and field, Badal Mondal finds a new role, not only as a cultivator, but also as a caretaker of a changing landscape. The land remains uncertain and vulnerable, but it is still alive. In learning to adapt with it rather than against it, he discovers that even loss can make way for renewal.



Source: Communication Department, PFRI

SOCIO-ECOLOGICAL ADAPTATION AND TRADITIONAL KNOWLEDGE SYSTEMS IN GANGASAGAR ISLAND

Mr. Jalad Kumar Gayen, Field Officer (PFRI)

Standing on the windswept shores of the Gangasagar Island, within the vast expanse of the Indian Sundarban, I was struck by how deeply human life here is shaped by water- its presence, its absence, and its salinity. As a long-time resident of the island, I offer a grounded perspective on how communities negotiate survival in one of the world's most dynamic wetland ecosystems.

Gangasagar is not only a site of religious significance but a fragile deltaic environment, crisscrossed by tidal creeks and rivers like the Muriganga, where low elevation, saline intrusion, waterlogging, and recurrent cyclonic disturbances shape everyday life. While these water bodies sustain fisheries and transport, their saline character limits freshwater availability and agricultural expansion.

Like many others on the island, my forefathers migrated from Medinipur, coastal Odisha, and different parts of the Sundarban in search of livelihood opportunities. But settlement here has always come with ecological constraints. Agriculture remains limited and largely rain-fed, with saline soils, flooding, and crop uncertainties restricting cultivation. Fishing, therefore, continues to be the primary livelihood, closely tied to the tidal rhythms of the surrounding rivers and estuaries.

One of the most striking features of life here is the community's reliance on artificially constructed ponds or tanks. As groundwater is saline even at shallow depths, rainwater harvesting has become a central survival strategy. In my locality alone, there are around nine such tanks. These are not merely water storage structures; they are part of a carefully managed local system in which water use is regulated to ensure availability throughout the year. In many cases, these ponds also support aquaculture, making them central to both household survival and local livelihoods.



What stands out in Gangasagar is the persistence of traditional ecological knowledge like salinity tolerant crop selection (salinity tolerant rice production and open crab fattening on the paddy field, seasonal vegetable farming for crop rotation), rainwater harvesting through ponds (storing rainwater in artificial ponds and tanks and separating them based on the usage like drinking, daily usage, brackish fish culture and irrigation), sustainable natural resource use (honey production, NTFPs, coconut, and paddy straw used to make byproducts) and conservation and human-wildlife coexistence practices (maintaining the buffer zones through bunding, preventing illegal fishing activity by making proper surveillance teams).

The role of state intervention is also visible. Government efforts to improve water access, embankment construction, and rural infrastructure have helped make the island more habitable.

Yet such measures are most effective when they strengthen, rather than displace, local knowledge systems that have sustained communities here over generations.

Gangasagar, therefore, offers more than a local story of hardship or adaptation. It reflects a broader reality of the Sundarban- a landscape where land and water remain in constant dialogue, and where survival depends on understanding that balance. The people of the island are not passive victims of environmental constraints, rather, they actively reshape their surroundings through a combination of traditional practices and selective modern interventions. In that sense, Gangasagar stands as a living example of socio-ecological resilience in a fragile and shifting delta.



Source: Communication Department, PFRI

SHRINKING GRASSLANDS AND CHANGING LIVELIHOODS:

A CASE STUDY OF THE SAHARIYA TRIBE IN MADHYA PRADESH

Mr. Sujay Bhattacharjee, Research Assistant (PFRI)

The Sahariya tribe is one of the most marginalized forest edge-grassland dependent communities in the Shivpuri-Sheopur region of central India. Traditionally, they lived in close association with dry deciduous forests and adjoining grasslands. Their livelihood system was a mix of seasonal agriculture, livestock grazing, and collection of forest and grassland resources, such as fodder, fuelwood, and minor forest produce (Sati, V. P., 2015).

In earlier times, grasslands provided open grazing spaces, supporting small herds of goats and cattle. The community followed informal rotational grazing and depended on local grasses for sustaining livestock, especially during dry seasons. Over the years, erratic rainfall and prolonged dry spells have reduced natural grass regeneration and intensified pressure on already degraded lands. Moreover, grasslands in regions like Shivpuri and Sheopur have been converted into agriculture or plantations, encroached upon, or brought under forest enclosures. Limited land tenure security and restrictions on forest access have further constrained their resource use (Joshi, A., et al., 2018). These changes have led to reduced access to common grazing lands, forcing many families of the Sahariya tribe to reduce livestock or depend on purchased fodder (Kabra, A. 2009; Jatav, R., et al., 2023).

Consequently, declining livestock productivity has pushed households towards wage labour and seasonal migration, gradually destabilizing their traditional livelihood systems (Patel, P. 2025).

The grasslands that once lay close to the village have slowly disappeared. Some areas have been converted into farms, while others are fenced under forest plantations. Ramlal Sahariya and his family, who live in a small village on the edge of the dry forests and open grasslands of the Shivpuri region, have depended on this landscape for generations. At sunrise, Ramlal steps out of his mud house with a wooden staff, calling out to his goats and a few cattle. His wife, Munni Bai, hands him a small cloth bundle of rotis. "The grass is not like before," he says quietly, as he leads the animals toward a distant patch of land. "We now walk farther every year." Ramlal remembers a time when tall native grasses were abundant, and grazing did not require long journeys. Now, he must move carefully, avoiding restricted zones and searching for whatever fodder remains. By mid-morning, he reaches a shrinking patch of open land where thin grasses grow between dry soil cracks. Alongside grazing, he keeps an eye out for edible plants and fallen twigs - small resources that still support his household. The animals graze slowly, often competing with herds from neighboring villages facing the same scarcity.

Yet, despite these hardships, Ramlal continues to rely on his traditional knowledge. He knows which grasses regrow after light rains, which areas retain moisture longer, and how to manage his small herd to survive the lean months. During the monsoon, when the land briefly turns green again, there is a sense of relief and renewal. As the sun sets over the dry grassland, Ramlal sits outside his home and reflects: “This land has always supported us. But now, it is changing, and we must change with it”.

Ramlal’s experience is not an isolated one. It reflects a wider pattern in which grasslands, because they are often undervalued in policy and administration, become vulnerable to conversion, enclosure, and competing land uses such as agriculture and plantations. For communities such as the Sahariya, this is not only an ecological loss but also a question of livelihood security, customary access, and tribal rights.

While forest protection remains important, responsible governance must also recognize that conservation cannot be sustained by excluding those who have long depended on these landscapes and understand them most closely.

In this sense, the future of grasslands lies not only in better ecological recognition, but also in more just governance that treats tribal communities as custodians of these ecosystems, with rights to use, manage, and protect them. In the wider global context of climate stress, biodiversity loss, and growing pressure on common lands, this is a reminder that conservation will be most durable where ecological protection is linked with community rights and stewardship.

References:

- Sati, V. P., (2015). Sahariya Tribe: Society, Culture, Economy and Habitation. Vol. 1 (1), Page:26-31 https://www.researchgate.net/publication/296901976_Sahariya_Tribe_Society_Culture_Economy_and_Habitation
- Kabra, A. (2009). Conservation-induced Displacement: A Comparative Study of Two Indian Protected Areas. *Conservation and Society*, 7, 249. <https://doi.org/10.4103/0972-4923.65172>.
- Jatav, R., & Ghanghat, S. (2023). Role of Non-Timber Forest Products (NTFPs) in the Livelihood in Sahariya Tribal Economy of Shivpuri district Madhya Pradesh, India. *International Journal For Multidisciplinary Research*. <https://doi.org/10.36948/ijfmr.2023.v05i06.10295>.
- Patel, P. (2025). Prevalence of Chronic Food Insecurity, Policies, and Redressal Patterns among the Indigenous community: A Case Study of Sahariya Tribe from India. *Journal of Indigenous Social Development*. <https://doi.org/10.55016/ojs/jisd.v13i2.79249>.
- Joshi, A., Sankaran, M., & Ratnam, J. (2018). ‘Foresteering’ the grassland: Historical management legacies in forest-grassland mosaics in southern India, and lessons for the conservation of tropical grassy biomes. *Biological Conservation*. <https://doi.org/10.1016/j.biocon.2018.05.029>.
- Interview record from Field worker of PRADAN

SHIFTING TIDES:

HOW CLIMATE CHANGE IS REDEFINING HABITAT AND LIVELIHOOD IN THE INDIAN SUNDARBAN

Ms. Shreya Ghosh, Admin Officer (PFRI)

Forty-year-old Sondha Mondal begins each dawn by walking a kilometre to fetch water from a distant pond. In this salt-ravaged coast even the most basic task has become a daily ordeal. Her story illustrates how traditional habitats and ways of life are under siege as sea levels rise and storms grow stronger. The Sundarban forms the world's largest contiguous mangrove forest. More than 4 million people inhabit the Indian part, living amid a maze of tidal rivers, mudflats and islets. These deltaic habitats provide unique ecological niches: villagers cultivate rain-fed rice on the low-lying fields and fish or collect honey and wood from the tidal creeks and mangroves. Most households still rely on subsistence farming supplemented by fishing, crab and honey gathering. In other words, local livelihoods are deeply embedded in the Sundarban's natural ecosystems.

A Landscape in Transition

Climate Stressors

In recent decades' climate change has sharply altered this landscape. Sea level in the Sundarban has risen at over 3 cm per year – more than twice the global average. Many small islands and embanked fields have already disappeared under the tide, and the coastline is retreating by tens of meters annually. The frequency of cyclonic depressions has also surged: one study found these storms 2.5 times more common in the past decade than before.

Each powerful cyclone (Aila 2009, Fani-Bulbul 2019, Amphan 2020, etc.) breaches earthen embankments and floods the delta with salty seawater, destroying crops and homes. Experts note that warming coastal waters are intensifying storms and flood surges. In short, rising seas, storm surges and land subsidence are converging to drown and salinize the Sundarban's lands.

Ecological Transformation

These stressors are converting fertile land into saline wasteland. Repeated flooding with seawater has poisoned once-productive rice fields. In some villages 'no longer support agriculture' at all. Thousands of hectares of paddy have been abandoned or turned into shrimp ponds. In fact, one case study in the Bangladesh Sundarban found more than 50% of a community's former farmland permanently flooded to raise shrimp. Meanwhile the mangrove forests themselves are weakening. A recent analysis estimates some 110 km² of Indian Sundarban mangroves eroded from 2000-2020, outpacing the area reforested. Forest density is declining by over 1% per year, shifting the mix toward salt-tolerant species.

This retreat is costly – roughly USD 3.3 billion in ecosystem services have been lost over 30 years, 80% of it from mangroves. Salinity has thus become a central disruptor: it leaches nutrients from soil, collapses freshwater sources, and undermines the ecological basis of farming and fishing.

Changing Livelihoods: From Stability to Survival

Traditionally, most families grew monsoon rice and fished in the creeks. They supplemented this with forest products like honey, nipa palm thatch and fuelwood. Today those stable livelihoods are breaking down. Crop losses and credit traps force many farmers to diversify or abandon farming. A growing number shift to intensive shrimp aquaculture, despite the long-term damage to soil. Others send family members away. Seasonal or long-term migration is now commonplace. An estimated 20% of villages report at least one migrant, and in some blocks every second family has a member working outside. Roughly 60% of the male labor force has migrated for work, often to cities or other states. Among these migrants, many men find work as construction laborers or in distant factories, while women often move locally (e.g. to Kolkata) to work as domestic or care workers.

In short, climate stress has forced either diversification or collapse of livelihoods. As one UN Women report notes, roughly four of every five households still farm or fish, but incomes are precarious. Today a farmer must often also be a day laborer, aquaculture worker or wage-earner in the city.

Migration and the Feminisation of Livelihood

As men leave home, women are shouldering more. Migration from the Sundarban remains predominantly male, but ‘more women are now joining’ the exodus as well. In fact, seven out of ten migrating women stay within West Bengal (often taking jobs in nearby cities or towns).

Those who stay behind often find themselves de facto heads of households. With husbands absent, women manage whatever farmland and aquaculture remain, plus household budgets. They juggle farm chores, childcare and finance with very limited support. The burden of adaptation is thus increasingly ‘feminised.’ Data show that 80% of working women in these islands are involved in agriculture, yet they have minimal access to credit or land rights. In practice, climate pressures and male migration mean mothers like Momotaj must stretch dwindling resources further than before.

Gendered Impacts of Climate Change

Climate change disproportionately burdens women. Water scarcity and salinity directly affect women’s health and sanitation. For example, one study finds that ‘limited access to water and rising salinity levels are associated with poor maternal health, menstrual hygiene issues, and increased vulnerability to waterborne infections’. Carrying heavy loads of brackish water strains pregnant women and mothers; salt-laden drinking water causes hypertension and anemia in coastal villages (over 80% of households in one study reported skin or stomach ailments from saline water).

Economically, women have the least options. Formal jobs and education are scarce, so they depend even more on unstable natural resources. As surveys note, ‘with men migrating for work, women struggle with increased labor burdens, reduced income and limited access to decision-making’ necessity.

Socially, drought and storms exacerbate traditional gender inequities: patriarchal norms limit women's land control and autonomy, and household disputes over scarce resources rise under stress. In sum, women's bodies and labour have become frontline sites of the climate crisis, even as their roles expand out of sheer necessity.

Human–Environment Conflict

Over-extraction of resources under climate stress is increasing conflict with wildlife and among communities. Tigers, notorious in the Sundarban, prey on fishermen and honey gatherers. One review found 789 human tiger-attack victims (666 fatally) in 1985–2009, averaging ~28 incidents per year. Most victims (80%) were people who harvested fish, crab or forest products. When floods and embankment breaches drive villagers deeper into the forest, encounters rise further. After Cyclone Amphan (2020) and COVID lockdowns, many say they 'had to depend on the forest again... venturing into the jungle despite knowing we may encounter tiger conflicts'. These dangers create tension: wildlife protections restrict forest entry, yet hungry families have 'no option' but to fish and gather in those same forests. In effect, the struggle for survival is pitting conservation rules against human need.

Indigenous Knowledge and Adaptation

People are not passive victims; many draw on traditional knowledge to cope. For example, local farmers have revived salt-tolerant rice varieties that ancestral growers used for centuries. After Cyclone Aila (2009) flooded fields with salt, a rice scientist reintroduced four native rice strains (Lal Getu, Sada Getu, etc.) that tolerate brackish soil.

These old varieties proved hardy and profitable, yielding grain without expensive fertilizers and even providing fodder. Today dozens of Sundarban families are cultivating these resilient strains again. Similarly, communities practice nature-based shoreline protection. In one Bangladeshi village, locals organized a mangrove plantation on eroded riverbanks, with the union council funding saplings and fencing. The new mangroves rapidly took root, stabilizing the soil and boosting fish nurseries. As residents note, "Mangrove plantations enhance coastal protection... [and] local community involvement in these efforts, paired with traditional knowledge, leads to more effective conservation". Such examples – salt-proof crops, mangrove buffers, seasonal crop rotations and diversified homestead gardens – reflect enduring Sundarban wisdom adapted to the new reality.

Policy, Development, and Gaps

Governments and NGOs have launched various adaptation measures, but gaps remain. West Bengal maintains ~3,500 km of earthen embankments around the Sundarban, yet many are over a century old and crumbling. A World Bank report warned that the decaying 19th-century dyke system may not withstand continued sea-level rise and stronger cyclones.



Source: Communication Department, PFRI

Disaster relief (shelters, food aid) and high-level plans exist, but local realities are often overlooked. For instance, top-down schemes sometimes fail to accommodate gender roles or local resource needs. On the other hand, NGOs like SEED India and Landesa are pioneering bottom-up solutions (saline farming training, women's self-help groups, community forestry). Still, formal policy rarely centers on climate justice: as one NGO study points out, only ~15% of Sundarban women control any financial resources, making it hard for them to recover from climate shocks. In short, top-down interventions must be complemented by locally-driven, gender-sensitive approaches to be effective.

Future Pathways: Rethinking Habitat and Niche

Paths forward will require integrated solutions:

- **Ecological:** Restore and protect the mangroves that shield the coast. Support projects that replant tidal forests and diversify local landscapes. Promote climate-resilient agriculture – for example, expanding salt-tolerant rice and vegetable varieties as introduced post-Aila. Implement sustainable watershed management to maintain freshwater flows.
- **Livelihood:** Create alternative income sources beyond resource extraction. For example, develop cottage industries (weaving, crafts) or ecotourism that can employ trained locals. Foster microenterprises in fisheries, poultry or agriculture that are less climate-sensitive. Training programs (like SEED's climate-smart farming workshops) should be scaled up to teach new skills in marketing, finance and sustainable practices

- **Social:** Mainstream women's leadership and rights. Climate adaptation plans must explicitly involve women – e.g. through women-led cooperatives for local enterprises. Strengthen community governance (village councils, SHGs) so residents have real voice in planning embankment repairs or relief priorities. Improve education and health services to buffer families against shocks.

Each of these paths is partly underway; what is needed is coherence and justice.

Conclusion

The story of the Sundarban today is one of profound change. Its habitat is literally shifting under people's feet, and the niches they have long occupied are no longer stable. The delta's mangroves, rivers and fields are still home to millions, but the rules have changed: prosperity and survival now hinge on adaptation. The answer lies in resilient, community-driven transformations – replanting mangroves, reviving ancestral crops, and empowering women's agency – so that habitat and livelihood can once again align sustainably. In the Sundarban, people are not simply losing land; they are redefining human existence within a changing habitat.

References:

Actual sources for the above include reported studies and articles on the Sundarban. For example, Mallick et al. (2021) quantify mangrove-dependent livelihoods, and Saha (2025) examines climate's gendered impacts. Journalistic and NGO reports (e.g. the Daily Star, UN Women/Thomson Reuters, Landesa) provide on-the-ground narratives. Scientific reviews document sea-level rise, salinity and mangrove loss. All cited works have been checked for authenticity.

News Hamlet



INDIA'S FIRST RAMSAR WETLAND CITIES:

PROMISE, PROGRESS, AND THE REALITY ON THE GROUND

Dr. Bhaskar Deb Bhattacharya, Senior Research Officer (PFRI)

India has entered a new chapter in urban ecological stewardship with the historic recognition of Indore and Udaipur as the country's first Ramsar Wetland Cities. The announcement, made under the framework of Ramsar Convention on Wetlands Resolution XII.10 (2015), places these cities among an elite global network of 43 accredited cities across 17 countries. The honour recognizes urban centres that successfully integrate wetland conservation into city planning—an urgent necessity in a world where nearly 35% of wetlands have been lost since 1970.

Wetlands are often described by ecologists as the 'kidneys of the landscape,' performing vital ecological services. Through complex microbial activity and plant-root systems, wetlands naturally filter pollutants, improve water quality, and regulate hydrological cycles. Scientific assessments, including those cited by the Intergovernmental Panel on Climate Change, highlight that wetlands can store carbon at rates significantly higher than many forest ecosystems. They also act as natural flood buffers, absorbing large volumes of excess rainwater—an increasingly valuable function as cities face intense rainfall events and urban flooding.

The recognition of Indore builds upon its longstanding reputation as one of India's cleanest cities. The city protects the ecologically significant Sirpur Lake, designated as a Ramsar site in 2023.

This lake supports more than 200 species of migratory and resident birds, making it a critical biodiversity refuge in central India. Restoration measures, including eutrophication control and habitat management, have strengthened the lake's ecological resilience. Urban climate studies suggest that water bodies such as Sirpur Lake help reduce urban heat by several degrees through evapotranspiration, providing relief in increasingly hot urban environments.

Meanwhile, Udaipur—often called the 'City of Lakes'—is known for its interconnected lake system, including Lake Pichola, Fateh Sagar Lake, and Swaroop Sagar Lake. These water bodies form a hydro-geological network that supports groundwater recharge and stabilizes water supply during erratic monsoon cycles. Scientific studies indicate that these lakes significantly contribute to aquifer replenishment, strengthening the city's resilience against drought and climate variability.

Under the Ramsar Wetland City Accreditation, cities receive international recognition for six years, along with increased opportunities for eco-tourism, research collaboration, and green investment. However, accreditation also brings responsibilities. Cities must monitor water quality, biodiversity health, and community participation while implementing restoration measures such as phytoremediation and sustainable land-use planning.

These actions align closely with global sustainability goals, particularly those focusing on water security and sustainable urban development.

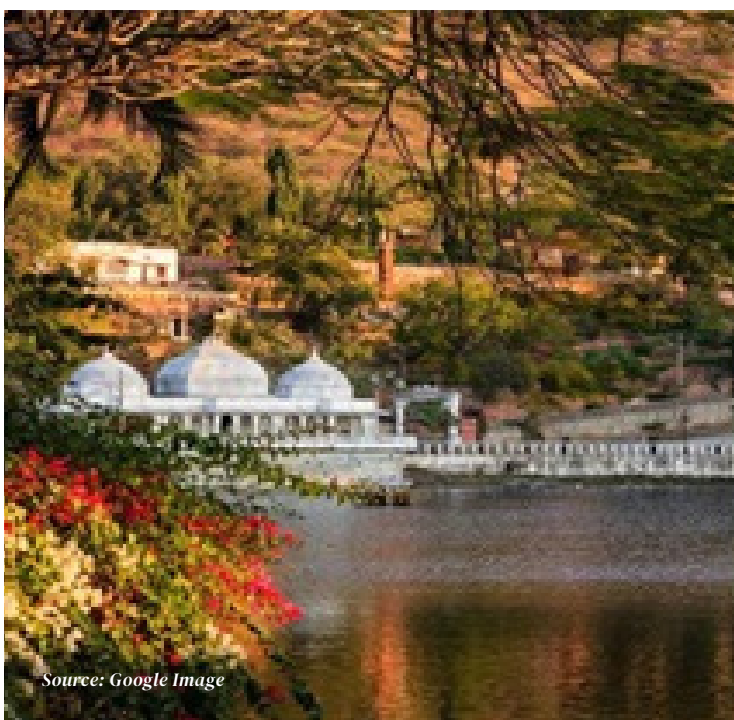
But an important question remains: Is Ramsar designation alone improving the real condition of wetlands?

Across India and globally, Ramsar recognition has raised visibility and awareness, but the ecological outcomes vary widely. In several wetlands, designation has led to better management planning, funding allocation, and stricter monitoring. In cities like Indore and Udaipur, visible improvements in cleanliness, lake restoration, and public engagement suggest that the Ramsar tag has created positive momentum.

However, conservationists caution that designation alone does not guarantee ecological recovery. Urban expansion, encroachment, untreated sewage inflow, and infrastructure pressure continue to threaten many Ramsar wetlands across India.

In some locations, wetlands remain under stress despite their protected status due to weak enforcement and fragmented governance. Marginalized communities living near wetlands often face the brunt of ecological degradation, highlighting the need for inclusive conservation approaches. The recognition of Indore and Udaipur is therefore both an achievement and a test. It demonstrates that cities can adopt nature-based solutions, yet it also underscores the responsibility to translate global recognition into measurable ecological improvements. As India's urban population continues to grow-projected to reach nearly 40% by 2030-the success of these first Ramsar Wetland Cities will shape the future of urban wetland conservation in the country.

Ultimately, Ramsar accreditation is not an endpoint but a beginning-an opportunity to prove that urban growth and ecological preservation can coexist, provided commitment extends beyond titles into sustained action on the ground.



LIMITATIONS OF SECONDARY SATELLITE DATA IN DYNAMIC WETLAND LANDSCAPES:

INSIGHTS FROM THE EAST KOLKATA WETLANDS

Mr. Somnath Samanta, Research Assistant (PFRI)

Secondary satellite data have become central to environmental research, land-use assessment, wetland monitoring, and spatial planning. Freely accessible platforms such as Google Earth are especially useful for preliminary mapping because they allow researchers to identify water bodies, vegetation patches, settlement expansion, and broad land-use patterns without immediate field access. However, in rapidly changing wetland landscapes, such datasets can also produce misleading representations of ground reality.

This limitation becomes particularly important in dynamic landscapes such as peri-urban wetlands, where ecological change and human-induced land conversion often occur faster than the update cycles of publicly available satellite imagery.

The East Kolkata Wetlands (EKW) provide a significant case through which this problem can be understood. Recognised as a Ramsar Site of international importance, the EKW constitute a distinctive socio-ecological system where wastewater treatment, nutrient recycling, aquaculture, agriculture, and local livelihoods are closely interlinked. However, their location on the edge of the Kolkata Metropolitan Area has made them highly vulnerable to encroachment, land conversion, settlement growth, and other anthropogenic pressures.

Recent field observations from selected locations in the EKW reveal a marked mismatch between secondary satellite-based representations and actual ground conditions. Several areas that continue to appear as water bodies on Google Earth have actually been converted, partially or fully, into agricultural land. In some locations, the transformation appears to be associated with filling, drying, or gradual conversion of wetland areas for cultivation and other land uses.





Figure 1: Location map of sample sites

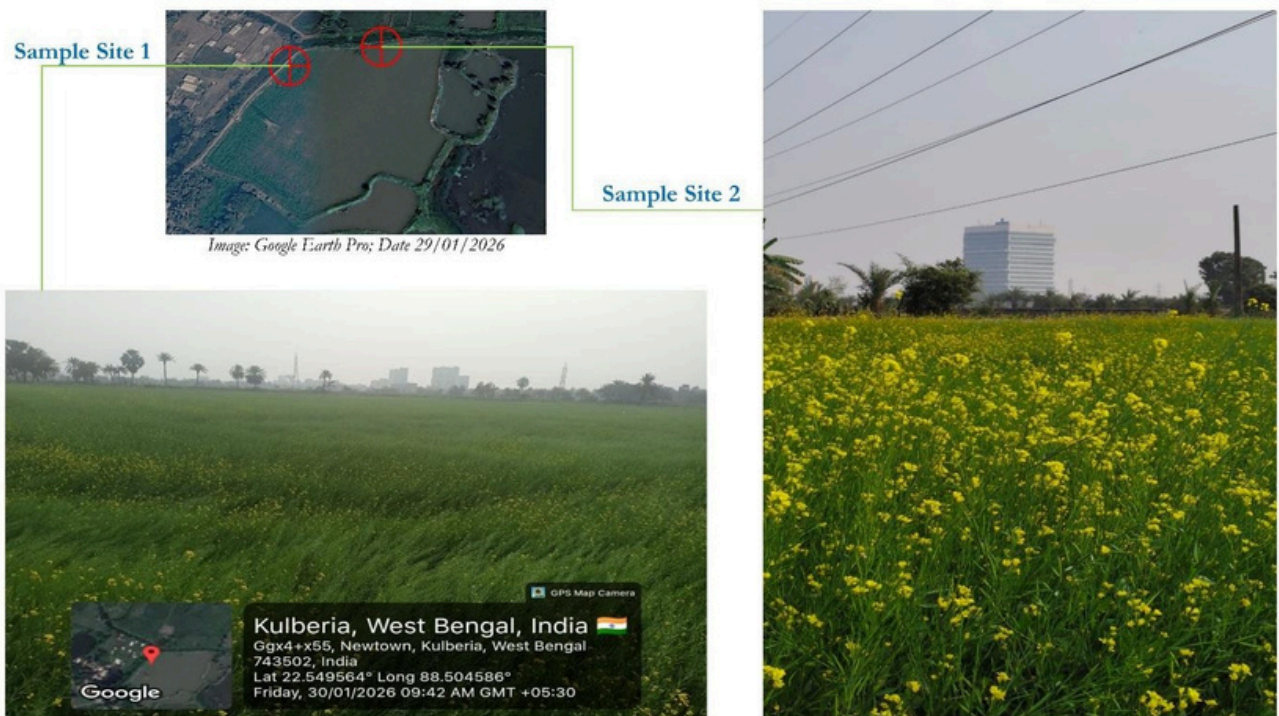


Figure 2: Deviation between secondary geospatial datasets and primary ground truth measurements

This discrepancy does not simply indicate an error in one digital platform. Rather, it reflects a wider methodological limitation in the use of secondary geospatial data for dynamic landscapes. Google Earth and similar platforms often rely on mosaicked imagery compiled from different dates and sources. The image visible to the user may therefore not represent the most recent ground condition. In wetlands undergoing rapid peri-urban transformation, even a short temporal lag can result in significant misclassification.

Seasonality further complicates the issue. Shallow wetland areas may appear differently across pre-monsoon, monsoon, and post-monsoon periods. A seasonally dry wetland may be interpreted as agricultural land, while an area temporarily holding water may be classified as a stable water body. Conversely, land that was historically under water may continue to appear as a wetland in older imagery even after being converted. These problems are especially pronounced where land-cover boundaries are fluid and where water, vegetation, soil moisture, and cultivation coexist in close proximity.

The mismatch observed in the East Kolkata Wetlands is not an isolated technical problem. It points to a broader challenge in environmental research—dynamic landscapes cannot be understood through secondary satellite data alone. Across wetland systems globally, especially those facing urban expansion, agricultural conversion, infrastructure pressure, and climate variability, remote sensing must be supported by ground verification and context-sensitive interpretation.

Otherwise, inaccuracies can affect wetland inventories, ecological vulnerability assessments, hydrological modelling, biodiversity studies, carbon assessments, and environmental impact evaluations. In planning contexts, they may also distort decisions related to conservation zoning, restoration priority, resource allocation, and enforcement.

To address such issues, an integrated methodological approach is required. High-resolution and frequently updated satellite imagery should be combined with multi-temporal analysis so that seasonal and long-term land use and land cover changes can be distinguished. Machine learning-based classification may improve accuracy, but only when supported by reliable training data and field validation. Regular ground surveys are essential for identifying recent land-use changes that have not yet appeared in secondary datasets. Participatory mapping with local communities can also provide valuable information on recent filling, cultivation, drainage changes, encroachment, and shifts in wetland use.



Progyan Foundation for Research and Innovation (PFRI)

Administrative Office: A30, Loknath Bhaban, Santoshpur, Kolkata – 700075 West Bengal, India

Phone: +91 8240031767

E-mail: office@progyanfoundation.org, info@progyanfoundation.org

Website: www.progyanfoundation.org