Climate Change in Eastern Himalayas

Contextual Insights from Northeast India

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Edited by

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Bharti Publications

New Delhi- 110002 (INDIA)

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Title: Climate Change in Eastern Himalayas: Contextual Insights from Northeast India

Editors: Abhinav Sankar Goswami, Bishal Bhuyan, Debajyoti Bhattacharjee

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First Published, 2026

ISBN: 978-81-17264-00-3

DOI: https://doi.org/10.70381/264003.2026

Published by :

Bharti Publications

4819/24, 2nd Floor, Mathur Lane

Ansari Road, Darya Ganj, New Delhi-110002

Phone: 011-46172797, 9899897381

E-mail : bhartipublications@gmail.com

info@bharatipublications.com

Website : www.bhartipublications.com

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Message

I am pleased to learn about bringing out the forthcoming edited volume titled "Climate Change in the Eastern Himalayas: Contextual Insights from Northeast India", conceptualised by the Internal Quality Assurance Cell (IQAC) of Majuli College. This timely scholarly initiative addresses one of the most pressing global challenges of our era through the vital lens of the Eastern Himalayan region, with special focus on Northeast India.

Climate change today is not merely an environmental concern; it is a complex and multidimensional challenge that intersects with ecology, society, economy, culture and governance. The Eastern Himalayas, with their rich biodiversity and fragile ecosystems, stand at the frontline of this crisis. The impacts are increasingly visible in the form of ecological vulnerability, changing rainfall patterns, soil erosion, biodiversity loss and disruptions to traditional livelihoods.

In this context, an interdisciplinary academic engagement such as this volume is both significant and necessary. By bringing together diverse perspectives on environmental change, indigenous knowledge systems, sustainable livelihood practices, governance frameworks and policy responses, this work promises to contribute meaningfully to contemporary climate discourse.

It also highlights the importance of contextual understanding—recognising that global problems must be addressed through locally grounded insights and region-specific strategies.

I am particularly encouraged by the emphasis on indigenous knowledge systems and community-based resilience, which have long been central to the ecological wisdom of Northeast India. Integrating such knowledge with modern scientific approaches can pave the way for more inclusive and sustainable solutions.

I sincerely commend the IQAC of Majuli College for conceptualising this important academic endeavour and for fostering interdisciplinary collaboration among scholars, academicians and practitioners. I hope, this volume will serve as a valuable resource for researchers, policymakers and students engaged in climate and environmental studies.

I extend my best wishes for its successful publication and anticipate that it will contribute significantly to advancing both scholarly understanding and practical action in addressing the challenges of climate change in the Eastern Himalayas.

Dated Dibrugarh, the 18th May, 2026



(Jiten Hazarika)

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Message

It gives me immense pleasure to present this edited volume, *Climate Change in Eastern Himalayas: Contextual Insights from Northeast India*, brought out under the aegis of the Internal Quality Assurance Cell (IQAC), Majuli College.

Living and working on Majuli, we do not just study climate change; we live through it. As the world's largest river island, this land constantly reminds us how delicate the balance is between the river and our daily lives. The shrinking banks, unpredictable floods and erratic weather are realities woven into our community's everyday existence. For us at Majuli College, climate research is not just an abstract scholarly pursuit; it is a deeply personal responsibility born of our own lived experience.

The Eastern Himalayas represent a vital ecological shield for the subcontinent, yet they remain uniquely sensitive to microclimatic shifts. This book represents a timely and significant endeavor to aggregate localized evidence, scholarly insights, and sustainable practices from across Northeast India. By assembling diverse perspectives from twenty-five dedicated researchers and practitioners, the volume captures the nuanced dimensions of environmental governance, indigenous adaptation strategies and ecosystem preservation.

We are deeply privileged to receive the inspiring message shared by Prof. Jiten Hazarika, the Hon'ble Vice-Chancellor of Dibrugarh University, as well as the generous support of Prof. Ramesh Chandra Deka, the Hon'ble Vice-Chancellor of Cotton University, who has graced this volume with his foreword.

I congratulate the IQAC team and the editors for their vision, perseverance and dedication in curating this important volume. May this publication stimulate meaningful academic inquiry, inform practical conservation initiatives, and inspire our youth to become active custodians of our shared natural heritage.

Dated Majuli, the 16th September, 2026



Dr. Debajit Saikia
Principal Majuli College

Foreword

Interdisciplinary Approaches to Climate Change in the Eastern Himalayas: Contextual Insights from Northeast India

Climate change has emerged as one of the defining challenges of our time, affecting natural systems, economies, livelihoods, public health, and the social fabric of communities across the world. Its consequences, however, are neither uniform nor geographically detached. They are experienced through particular landscapes, ecological systems, cultural practices, and patterns of human dependence on nature. The Eastern Himalayan region, with its extraordinary biological diversity, complex terrain, rich river systems, and distinctive social and cultural traditions, therefore deserves sustained and context-sensitive scholarly attention.

Northeast India occupies a particularly important place within this larger ecological landscape. The region is endowed with remarkable forests, wetlands, riverine ecosystems, agricultural diversity, and biological resources, while at the same time remaining highly sensitive to environmental change. Alterations in rainfall patterns, increasing climatic variability, floods, erosion, landslides, changes in biodiversity, pressures on forests and water resources, and emerging challenges to agriculture and livelihoods demonstrate that climate change cannot be understood merely as a problem of atmospheric science. It is simultaneously an ecological, economic, social, cultural, technological, and developmental concern.

It is in this context that the peer-reviewed edited volume, Interdisciplinary Approaches to Climate Change in the Eastern Himalayas: Contextual Insights from Northeast India, being published by the Internal Quality Assurance Cell of Majuli College, is timely and assumes considerable significance. The very conception of the volume recognizes an essential feature of the climate challenge: no single discipline can adequately explain its causes, consequences, or possible solutions. Meaningful understanding requires dialogue among the natural sciences, social sciences, humanities, economics, geography, environmental studies, public policy, technology, and the knowledge systems of local communities.

An interdisciplinary approach is particularly relevant to Northeast India, where ecological processes and human life are intimately interconnected. Rivers and wetlands influence settlement and agriculture; forests sustain biodiversity as well as livelihoods; climatic variability affects food security and rural economies; and environmental transformations interact with migration, infrastructure, health, culture, and traditional ways of life. Scientific observations and technological interventions are indispensable, but their effectiveness ultimately depends upon an understanding of local realities, community participation, institutional capacity, and the social contexts in which adaptation and mitigation measures are implemented.

The Eastern Himalayas also remind us that sustainability must be approached not only as a scientific objective but as an ethical and developmental responsibility. Economic progress and improvement in human well-being are necessary, yet development must be pursued without undermining the ecological foundations upon which future generations will depend. The challenge before us is therefore to find pathways that reconcile development with conservation, innovation with ecological responsibility, and contemporary scientific knowledge with valuable place-based and traditional knowledge.

In this regard, institutions of higher education have an important responsibility. Colleges and universities are not merely centres for transmitting established knowledge; they must also become spaces where emerging challenges are critically examined, disciplines interact, local problems are connected with global processes, and young people are encouraged to participate in the search for sustainable solutions. Research originating from regional institutions can make an especially valuable contribution because it is often grounded in close familiarity with local environments, communities, and lived experiences.

Majuli itself provides a compelling setting from which to reflect upon these questions. As a riverine landscape of exceptional ecological and cultural significance, it offers a powerful reminder of the close relationship between environment, society, heritage, and human resilience. An academic initiative emerging from Majuli College can therefore contribute meaningfully to wider conversations on climate vulnerability, adaptation, sustainability, and the future of the Eastern Himalayan region.

I appreciate the initiative of the Internal Quality Assurance Cell of Majuli College in bringing together scholars and perspectives through this edited volume. Peer-reviewed interdisciplinary publications of this nature can stimulate informed discussion, identify areas requiring further research, strengthen collaboration among institutions and disciplines, and help connect academic inquiry with policy and community concerns. I hope that the contributions in this volume will encourage readers not only to understand climate change in its regional complexity but also to think constructively about locally appropriate and scientifically informed responses.

The climate challenge demands knowledge, cooperation, imagination, and a long-term sense of responsibility. For Northeast India, solutions must emerge from a careful understanding of its unique ecological characteristics and developmental aspirations. The region should not merely be viewed as vulnerable to climate change; its biodiversity, community knowledge, cultural traditions, scientific institutions, and young population can also make it an important source of ideas and models for sustainable and resilient development.

I congratulate the editors, contributors, the Internal Quality Assurance Cell, and the entire team of Majuli College associated with this scholarly endeavour. I am confident that this volume will serve as a useful resource for researchers, teachers, students, policymakers, environmental practitioners, and all those concerned with the future of the Eastern Himalayas and Northeast India.

I wish *Interdisciplinary Approaches to Climate Change in the Eastern Himalayas: Contextual Insights from Northeast India* every success and hope that it will inspire further research, interdisciplinary collaboration, and responsible action towards building a more sustainable and resilient future.

Prof. Ramesh Chandra Deka

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Editorial

Climate change is among the most consequential challenges confronting the contemporary world, but its manifestations are neither uniform nor detached from place. The changing climate is experienced through altered rainfall, recurrent floods, landslides, ecological degradation, livelihood insecurity, displacement and transformations in cultural landscapes. In the Eastern Himalayas, these processes acquire particular urgency because environmental sensitivity is closely entangled with extraordinary biological diversity, complex terrain, rich cultural traditions and the dependence of communities on natural resources. Northeast India, occupying a distinctive position within this landscape, provides an important context to examine the multiple dimensions of climate change and the varied ways in which societies understand and respond to it.

It is against this backdrop that Climate Change in the Eastern Himalayas: Contextual Insights from Northeast India brings together a range of perspectives that collectively broaden our understanding of climate change. The volume moves beyond a narrowly scientific interpretation of climatic transformation and considers the phenomenon as an interconnected ecological, social, political, cultural and human experience. Its underlying premise is that no single discipline can adequately capture the complexity of environmental change in a unique region such as this. It is a region where mountains, rivers, communities, institutions, knowledge systems and cultural practices are deeply interdependent.

One of the most compelling insights emerging from the volume is the importance of place-based knowledge and community resilience. The experience of Majuli is particularly instructive in this regard. Living with perennial floods and riverbank erosion has required communities to develop adaptive practices based on generations of observation and interaction with the riverine

environment. Traditional ecological knowledge is embedded in housing practices, livelihood strategies, agricultural choices, resource use and social organisation. Such knowledge represents not merely a historical inheritance but a dynamic resource for contemporary climate adaptation. Several research studies on Majuli demonstrate and validate such observations.

The significance of such insights extends well beyond Majuli. Climate adaptation policies are often conceived through technological and infrastructural interventions. In contrast, the knowledge of communities that have long negotiated environmental uncertainty may receive inadequate recognition. The volume encourages a more balanced approach in which scientific expertise and indigenous knowledge are not positioned as competing systems but as potentially complementary sources of understanding. This is particularly relevant in the Eastern Himalayas, where local communities possess detailed knowledge of landscapes, seasonal cycles, water systems and ecological changes. Contemporary scholarship increasingly recognises traditional ecological knowledge as an important component of socio-ecological resilience in Northeast India.

A second major insight concerns the centrality of rainfall and hydroclimatic variability to the environmental future of the region. Rainfall is not simply a climatic statistic in the Eastern Himalayas; it is a fundamental determinant of agriculture, water resources, biodiversity, infrastructure and disaster risk. Historical examination of rainfall patterns, therefore, provides an essential foundation for understanding current and emerging vulnerabilities. Recent research across Northeast India indicates considerable intra-regional variation in rainfall and changing patterns of variability, reinforcing the need for locally and regionally differentiated adaptation strategies. The volume's engagement with historical rainfall trends and forecasting together establishes an important continuum between understanding the past and preparing for the future. Historical climatic records help identify patterns and fluctuations, while monitoring and forecasting provide tools for anticipating future conditions. In a mountainous region characterised by highly variable topography and complex atmospheric processes, this becomes particularly significant. The ability to track rainfall changes and improve forecasting can strengthen early-warning

systems, thereby facilitating agriculture planning, water management, infrastructure and disaster preparedness.

Yet the volume also draws attention to an important limitation of scientific prediction. Climate information has little practical value unless it is effectively communicated and translated into decisions. Forecasts must ultimately reach communities and administrators who can use them to reduce risk. This places climate science within a broader framework of governance and social responsibility. The challenge is therefore not simply to generate more data but to create effective pathways through which knowledge can inform action.

This leads naturally to another central theme of the book, the governance of environmental change across political and geographical boundaries. The Eastern Himalayas constitute a complex political space in which ecological systems frequently transcend administrative and national borders. Rivers, watersheds, forests, biodiversity and climatic processes cannot be contained within political boundaries. Consequently, climate change introduces a need for forms of cooperation that extend beyond conventional approaches to territorial security.

The idea of moving from a security-oriented understanding towards a governance complex is particularly valuable. Environmental security cannot be addressed solely through conventional state-centric mechanisms. Shared rivers, climate-induced hazards, ecological degradation and changing patterns of human vulnerability require cooperation among governments, research institutions, local communities and civil society. Regional cooperation must increasingly encompass information sharing, scientific collaboration, disaster management, water governance and ecological conservation. Such an approach also challenges the tendency to treat environmental issues as secondary to geopolitical concerns. In reality, ecological interdependence can itself become the basis for cooperation. The Eastern Himalayas demonstrate that environmental governance is inseparable from questions of regional stability and human security. A more cooperative regional framework can transform shared environmental vulnerability into an opportunity for dialogue and collective action.

Another significant contribution of the volume is its persistence that climate change is also a cultural and imaginative experience.

Scientific data can establish that temperatures or rainfall patterns are changing. However, numbers alone cannot fully convey what those changes mean to people whose identities and memories are connected to particular landscapes. Rivers, mountains, forests and wetlands are not merely physical entities; they can be repositories of cultural memory, spiritual meaning, literary imagination and collective identity. The intersection of culture, literature and climate therefore provides a valuable expansion of the conventional climate discourse. Narratives allow environmental change to be understood through memory, emotion, displacement, belonging and loss. They can reveal how communities interpret transformations in landscapes and how changing environments affect relationships between people and place. Literature, oral traditions and other cultural forms thus constitute important modes of environmental knowledge.

This perspective is especially significant in the Eastern Himalayas because of the region's extraordinary cultural diversity. Climate change can alter not only livelihoods and ecosystems but also the cultural landscapes through which communities understand themselves. When a river changes course, a village is displaced, a forest disappears or agricultural practices are transformed, the consequences may extend into language, memory, tradition and identity. Thus, recognising these dimensions enables climate scholarship to move beyond an exclusively material understanding of vulnerability.

The volume simultaneously maintains a strong engagement with the physical and chemical dimensions of environmental change. Its attention to chemical and environmental dynamics underscores the fact that climate change operates within a wider network of atmospheric, hydrological, biological and chemical processes. Environmental degradation, pollution and anthropogenic pressures can interact with climatic variability leading to an impact on ecosystems and human well-being.

It is this interplay between different forms of knowledge that gives the volume its distinctive character. Climate change emerges not as a collection of isolated problems but as a complex socio-ecological system. Floods have hydrological causes but social consequences. Changing rainfall is a climatological phenomenon but also an agricultural and economic concern. Environmental degradation may be measured through scientific

indicators but it can also simultaneously threaten cultural practices and community identities. Regional cooperation may begin as a political necessity but can evolve into an ecological imperative.

Taken as a whole, Climate Change in the Eastern Himalayas: Contextual Insights from Northeast India attempts to take readers through a natural progression, from what people live and observe to hard science, future planning and the deeper cultural values at stake. Its diverse perspectives converge around a shared question—how can societies living in environmentally sensitive landscapes respond to a changing climate without losing their ecological knowledge, cultural identity and community relationships?

The importance of the volume lies precisely in its refusal to provide a single answer. Instead, it encourages us to recognise the plurality of ways in which climate change is known and experienced. The riverine community, the climatologist, the environmental scientist, the political ecologist, the policymaker and the literary scholar may speak different languages, but they are ultimately addressing dimensions of the same changing landscape. The Eastern Himalayas demand such a conversation. Its environmental future will depend not only on better models, improved forecasts or stronger infrastructure. It will also depend on the ability to connect scientific knowledge with community experience, regional governance with ecological interdependence and environmental policy with cultural understanding. This volume is, therefore, more than a collection of studies on climate change. It is an invitation to rethink the way climate change itself is approached. It reminds us that the climate crisis is simultaneously a crisis of ecosystems, livelihoods, institutions and knowledge. In bringing these perspectives together, the volume contributes to a growing body of scholarship that seeks not merely to document only environmental transformation but to understand its meanings and possibilities.

This publication was made possible through the visionary support of the Internal Quality Assurance Cell (IQAC), Majuli College. We take this opportunity to express our sincere gratitude to Dr. Debajit Saikia, Principal of Majuli College, for his constant guidance and encouragement. We are deeply grateful to Prof. Jiten Hazarika, Hon'ble Vice-Chancellor of

Dibrugarh University, for penning a thoughtful message for this volume; and we remain indebted to Prof. Ramesh Chandra Deka, Hon'ble Vice-Chancellor of Cotton University, for writing the foreword. Our heartfelt thanks go to our distinguished editorial advisors across institutions in India and abroad for their insightful reviews of the drafts. We are also thankful to Mr. Basanta Borah, the IQAC Coordinator of Majuli College, for his constant cooperation. Special gratitude is extended to Anubhav Shankar Goswami for his valuable suggestions and advice on the cover page design. We also thank our colleagues, particularly Dr. Shahnaz Ahmed and Bidisha Bhattacharyya for their invaluable support throughout this process. Furthermore, we are equally grateful to the contributing authors for their timely submissions and cooperation. We gratefully acknowledge the support of the Star College Scheme under the Department of Biotechnology, Government of India. Finally, we thank Bharti Publications, New Delhi, for bringing this volume to print.

Editors

Abhinav Sankar Goswami

Bishal Bhuyan

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1

Climate-Driven Chemical Processes in The Eastern Himalayas

Sourav Boruah*[1], Shashwata Pratim Borah[2]

ABSTRACT

The Eastern Himalayas are undergoing rapid environmental transformation driven by warming rates of 0.2–1.0°C per decade alongside erratic precipitation regimes. This chapter synthesizes recent literature to evaluate how climate-induced cryospheric and hydrological shifts alter the chemical composition of regional air, soil, and freshwater networks, while assessing downstream consequences for dependent high-elevation communities. Accelerating glacier retreat and permafrost degradation release sequestered heavy metals and legacy pollutants into fragile aquatic systems, while shifting precipitation dynamics disrupt seasonal river discharge. Concurrently, elevated temperatures stimulate microbial activity, accelerating greenhouse gas emissions and destabilizing regional carbon–nitrogen dynamics. These disruptions drive widespread soil acidification, nutrient depletion, and water quality degradation across alpine forests, wetlands, and river basins, with intensifying wildfire activity further deteriorating ambient air quality.

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Crucially, local observations regarding erratic seasonal phenology, dwindling water supplies, and declining crop yields closely correspond with empirical biogeochemical datasets. By delineating key research gaps, this synthesis highlights the acute vulnerabilities confronting montane subsistence livelihoods and demonstrates the indispensable role of environmental chemistry and sustained, interdisciplinary monitoring in formulating resilient climate adaptation frameworks for the Himalayan cryosphere.

Keywords: *Eastern Himalayas, Climate Change Adaptation, Environmental Chemistry, Cryospheric Degradation, Biogeochemical Cycling*

1. Introduction

The Eastern Himalayas stand out as one of the planet's most delicate and ever-changing ecosystems, serving as a vital lifeline for water and the environment in Northeast India and neighbouring areas across borders. With its rugged terrain, incredible variety of life, and unstable rock structures, this region reacts quickly to shifts in climate (IPCC, 2023; Xu et al., 2009). Over the past few decades, climate change has become the main driver transforming not just the physical features of the land but also the chemical reactions that affect air, water, and soil. Getting a handle on these chemical and environmental interactions is key to figuring out how stable the ecosystems are, how they impact people's lives, and how we can ensure long-term sustainability in the Eastern Himalayas (Immerzeel et al., 2020).

In this area, climate change shows up as steadily climbing temperatures, unpredictable rainfall, and more frequent extreme weather like storms or droughts. Data from various studies reveal that warming here is happening faster than the worldwide average, speeding up glacier melt and messing with the frozen landscapes (Bolch et al., 2019; Shrestha et al., 2012). These shifts have a real impact on the chemistry of the environment, messing with stuff like what's in the air we breathe, the chemical balance in the ground, the natural processes in rivers and lakes, and the way nutrients cycle through everything. When temperatures rise and water patterns change, it affects how nutrients, metals,

and even pollutants shift around and react, which ultimately throws off how ecosystems function from low valleys up to high mountain spots (Balestrini et al., 2014).

Environmental chemistry acts as a crucial bridge, connecting these physical climate changes to the biological and ecological effects we see. For instance, increases in airborne particles, greenhouse gas releases, and smoke from wildfires can worsen air quality and trap more heat in the region (Ramanathan et al., 2007; Singh et al., 2020). At the same time, warmer conditions and changing soil moisture speed up rock breakdown, the rotting of organic material, and the washing away of nutrients, which can make soils more acidic and less fertile (Brady & Weil, 2016). Water systems, from rivers fed by glaciers to wetlands and mountain lakes, end up with different chemical mixes because of more runoff, melting ice, and stirred-up contaminants—this puts water quality at risk and threatens the lives of people downstream (Hood & Berner, 2009; Milner et al., 2017).

Even though this region is so important ecologically, the chemical side of climate change here does not get enough attention, with most research focusing on physical changes or biological shifts instead. This piece aims to fill that void by pulling together insights from local and international studies to look at how climate drives these chemical processes and the loops they create. It points out the big gaps in what we know and stresses the need for cross-discipline teamwork and monitoring across borders. Ultimately, it shows why environmental chemistry is essential for crafting smart strategies to adapt to climate change and manage resources sustainably in the Eastern Himalayas.

2. Regional Setting of the Eastern Himalayas

The Eastern Himalayas constitute a dynamic and ecologically exceptional segment of the Himalayan arc, extending from the Arun River gorge in eastern Nepal through Sikkim and northern West Bengal, across Bhutan, and into the Tsangpo–Brahmaputra valley, with peripheral influence from southwest China and northern Myanmar (Sultan et al., 2022; Ahmad et al., 2025; Bhattacharya et al., 2019). The region is characterised by extreme elevational gradients, rising from tropical lowlands at ~300 m to peaks exceeding 8,000 m, including Kangchenjunga, thereby compressing sharp climatic transitions across short spatial scales

(Ahmad et al., 2025; Khan et al., 2022). Geologically young and tectonically active, the Eastern Himalayas comprise a sequence of Himalayan structural belts—from the Siwalik foothills to the Lesser, Greater, and Tethyan Himalayas—situated within the highly dynamic "Third Pole" region, where ongoing plate convergence generates steep, unstable slopes prone to rapid erosion and mass wasting (Ahmad et al., 2025; Singh & Singh, 1987; Yao et al., 2024). Located directly in the path of moisture-laden monsoon systems from the Bay of Bengal, the region receives exceptionally high annual precipitation, locally exceeding 3,800–4,000 mm, which sustains a continuum of ecosystems ranging from dense tropical forests to temperate, subalpine, and alpine zones (Ahmad et al., 2025; Singh & Singh, 1987; Khan et al., 2022).

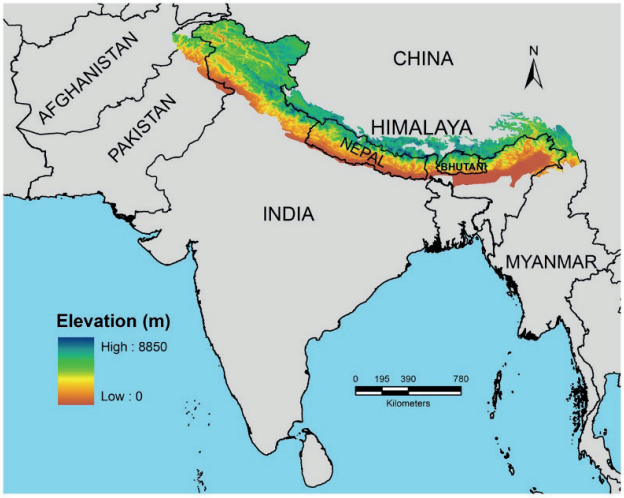


Fig 1: Spatial spread of the Himalayan mountain system across seven nations (https://doi.org/10.7717/peerj.5919/fig-1)

This convergence of steep topography, intense monsoonal rainfall, and persistent tectonic activity renders the Eastern Himalayas highly susceptible to natural hazards such as landslides, floods, and slope failures, whose frequency and intensity are strongly modulated by seasonal climatic variability (Yao et al., 2024; Panmei et al., 2025; Tse-ring et al., 2010). Ecologically, the region represents both a global centre of biodiversity and a recognised conservation "crisis zone," where Indo-Malayan, Palearctic,

and Sino-Japanese biogeographic realms intersect, giving rise to exceptional levels of species richness and endemism across ecosystems ranging from evergreen forests to alpine meadows (Khan et al., 2022; Ahmad et al., 2025; Bhattacharya et al., 2019). At the same time, communities inhabiting these remote mountain landscapes remain deeply dependent on forest and river systems for livelihoods and cultural continuity, thereby intensifying their vulnerability to climate-induced stresses and anthropogenic pressures that increasingly threaten the region's ecological and social resilience (Bhadwal et al., 2019; Negi et al., 2021; Tse-ring et al., 2010).

3. Climate Change Trends in the Eastern Himalayas

The Eastern Himalayas stand out as one of the most vulnerable spots in South Asia when it comes to climate change. This area is warming up faster than the global average, and its weather patterns are becoming more unpredictable. Based on weather records and studies, temperatures in this region have been rising steadily, with increases of approximately 0.2°C to 1.0°C every decade—especially noticeable at higher elevations in the mountains (Shrestha et al., 2012, pp. 704–708; IPCC, 2023, p. 51). This faster warming at higher elevations affects everything from ice and snow stability to how ecosystems work and even chemical reactions in the environment.

Rainfall in the region has gotten more irregular too. The monsoon might start at different times, heavy downpours are happening more often in short bursts, and dry periods are stretching longer. While the total yearly rain varies a lot from place to place, extreme rain events are on the rise, leading to more runoff, soil washing away, and chemicals leaching into the ground (Goswami et al., 2006, p. 153; Krishnan et al., 2020, p. 214). These shifts impact how nutrients move around, how sediment gets carried in rivers, and how pollutants spread in land and water. Intense rains also trigger more landslides, which expose new rock surfaces and accelerate natural chemical breakdown processes.

One of the clearest signs of climate change here is what's happening to the ice and snow. Glaciers are retreating quicker, snow cover is shrinking, and permafrost is thawing out—all observed in recent decades (Bolch et al., 2019, pp. 221–224). This

changes when and how meltwater flows into rivers, releasing more dissolved minerals, trace metals, and old trapped pollutants into the water (Bolch et al., 2019, p. 226). Over time, this could harm water quality and ecosystems downstream.

Beyond the physical changes, warmer temperatures are boosting biological and chemical activities in the soil. Microbes become more active, and soil "breathing" (releasing gases) ramps up. This leads to faster breakdown of organic matter, pumping out more carbon dioxide and nitrous oxide, while shaking up stored carbon and nitrogen (Schuur et al., 2015, pp. 59–61). These loops make climate change worse and alter the chemistry in soils and water across different heights in the mountains.

In summary, the Eastern Himalayas are dealing with a mix of rising heat, changing water cycles, and melting ice and snow. These patterns are the key forces behind the chemical and environmental shifts covered in the rest of this chapter.

4. Atmospheric Chemical Dynamics in a Changing Climate

Atmospheric chemical processes are like the unseen connectors between climate and the environment in the Eastern Himalayas—a stunning but fragile region now hit hard by pollution from nearby sources and winds carrying it from afar. As climate change ramps up, it's tweaking wind patterns, the air layers near the ground, and rainfall habits, which messes with how much and what kind of tiny particles (aerosols) and gases linger in the air, what they're made of, and how long they stay (Ramanathan et al., 2007, pp. 576–578). This isn't just tech talk; it directly hurts the air we breathe, traps more heat, and stresses ecosystems from lush valleys to icy peaks.

A major headache is the buildup of aerosols like black carbon (soot), organic stuff, sulfates, and nitrates. These hitch a ride from burning wood, car fumes, farmers setting fire to crop waste, and dirty air drifting in from the crowded Indo-Gangetic Plain (Lawrence & Lelieveld, 2010, pp. 102–104). When black carbon settles on snow or glaciers, it's like painting them dark—it soaks up sunlight better, melts the ice quicker, and cranks up the heat in a nasty loop unique to these lofty mountains (Lawrence & Lelieveld, 2010, p. 105).

Wildfires are getting wilder and more common in this hotter, drier world, adding to the chaos. Their smoke spews aerosols

and nitrogen compounds like NOx and ammonia, thickening hazy skies and raining extra nitrogen down on the land (Singh et al., 2020, pp. 6–8). That overload tweaks soil and plant chemistry, upsets natural balances, and can turn pristine high-mountain lakes and meadows into overgrown messes from too much "fertilizer." It also sours the rain, acidifying soils and stirring up metals in forests, which trickles into streams and harms wildlife.

Greenhouse gases—CO2, methane, and nitrous oxide—are tangled up in this air chemistry mess too. Warmer temps boost natural releases from soggy wetlands and forest dirt, while chopping trees or sparking more fires pumps out even more (IPCC, 2023, pp. 62–64). Methane from thawing permafrost and high-up bogs is especially worrisome—it's a potent heat-trapper that feeds back into more warming, like a snowball rolling downhill.

In the end, these climate-fueled air changes are rewiring how the sky, ice, and living world mingle in the Eastern Himalayas. They're not only supercharging local heat but also rippling out to mess with land and water chemistry. It's a wake-up call for better air watching and teaming up across borders to curb pollution—before it's too late for this breathtaking corner of our planet.

5. Soil and Terrestrial Chemical Processes under Climate Change

The soils in the Eastern Himalayas are like fragile guardians of life—thin, rich in organic goodies, clinging to steep slopes, and battered by fierce rains. But climate change is throwing them off balance, tweaking temperatures and wetness that mess with how rocks break down, nutrients flow, and pollutants move through the land. Warmer weather speeds up chemical reactions and wakes up soil microbes, breaking down organic matter faster and shifting key nutrients like nitrogen, phosphorus, and sulfur, which plants desperately need (Brady & Weil, 2016, pp. 421–424).

A big worry is that soils are turning more acidic. Heavier rains and soggier spells wash away helpful bases like calcium, magnesium, and potassium, leaving soils less able to fight back (Balestrini et al., 2014, pp. 461–463). This sourness frees up toxic aluminium and heavy metals, stunting roots, starving plants, and hitting forests and high meadows hard—places with little soil to spare.

Warmer, wetter conditions also crank up rock weathering, dissolving minerals and pumping out more silica, bicarbonate, and traces into ecosystems (Gabet et al., 2008, pp. 190–192). Sure, this could trap carbon long-term, but wild rains erode topsoil fast, hauling away nutrients and hitching contaminants along for the ride.

Plus, melting permafrost and wetter grounds stir up trapped metals and old pollutants, making them active again and sneaking them into rivers (Schuur et al., 2015, pp. 60–62). Deforestation, ramped up by climate woes, strips away protective organic layers and flips soil chemistry upside down.

In essence, climate's grip is rewriting these soils' story through heat, water, and land shifts—rippling out to weaken plants, dim ecosystems, and taint downstream waters. It's a call to action: we need ongoing soil checks and smart land care to protect this vital lifeline.

6. Aquatic and Riverine Biogeochemical Dynamics

In the breathtaking Eastern Himalayas, where glacier-fed rivers like the Brahmaputra, Teesta, and Subansiri carve through misty valleys, and serene wetlands, floodplains, and high-altitude lakes dot the landscape, something profound is shifting. Climate change is stirring up rapid changes in the very chemistry and biology of these waters, much like a quiet storm reshaping a familiar home (Bolch et al. 2019: 223–226).

Rising temperatures, erratic rains, and melting ice are tweaking how rivers flow—speeding up in some seasons, slowing in others. This means more meltwater rushes in during warmer months, altering the water's saltiness, nutrient mix, and even the mud it carries. Imagine glaciers retreating like fading memories, releasing a surge of fresh water that changes everything downstream.

One big worry is the release of hidden elements into the rivers. Warmer weather ramps up rock breakdown and erosion, freeing up stuff like calcium, magnesium, bicarbonate, iron, and silica. This boosts the water's ability to neutralize acids, but it's a double-edged sword (Hood & Berner 2009: 3–5). Thawing permafrost—those frozen soils acting as nature's deep freeze—unleashes old pollutants, including mercury and heavy metals trapped for ages, potentially poisoning drinking water and harming fish and wildlife (Schuur et al. 2015: 61–62).

Nutrients are getting a shake-up too. Fiercer monsoons wash more nitrogen and phosphorus from lands into these waters, risking overgrowth of algae in wetlands and floodplains—what we call eutrophication. This can spark bursts of plant life but also suck oxygen out, stressing creatures that call these places home (Balestrini et al. 2014: 463–465).

Warmer waters hold less oxygen, like a stuffy room, making it hard to breathe, worsening low-oxygen spots in dry times. Plus, more organic matter from eroding lands fuels bacteria, pumping out CO2 and methane—turning these rivers and wetlands into unexpected contributors to global warming (ibid 466).

In the end, these shifts are like ripples in a pond, affecting ecosystems, clean water for communities, and lives far downstream. It's a call for us to watch closely and manage these watersheds together, before the changes become irreversible.

7. Biogeochemical Cycles and Microbial Feedback Mechanisms

In the majestic Eastern Himalayas, where ancient peaks nurture vibrant ecosystems, the delicate ballet of biogeochemical cycles—the life-sustaining flows of carbon, nitrogen, and phosphorus—depends on climate's subtle cues. Temperature and moisture act as unseen guides, steering microbial bustle and the journey of elements across soil, water, and air. But climate change is disrupting this harmony, sending waves of change through forests, rivers, and farther afield, fueled by microbes ramping up their pace in breaking down organic material.

Warmer skies energize enzymes in soil microbes, much like stoking a fire, quickening the rot of hidden plant debris and unleashing more CO_2 and greenhouse gases upward (Schuur et al. 2015: 58–60). It's a self-feeding spiral, where this added warmth sparks even greater transformations, cranking up the region's temperature dial.

The carbon cycle feels this most deeply, capturing the essence of Earth's rhythmic breath as carbon weaves between atmosphere, earth, flora, and streams. Plants inhale CO_2 through photosynthesis, weaving it into their essence for growth and storage; when they wither, soil microbes dismantle it, exhaling CO_2 in respiration. In marshy lowlands and softening permafrost, low-oxygen environments prompt bacteria to brew methane—a fierce heat-trapper. Rising heat makes soils pant out more

carbon, eroding the steadfast reserves in mountain meadows (ibid 61). Permafrost melts away like forgotten snow, liberating age-old carbon for microbes to convert into methane amid soggy grounds. Wetlands and floodplains waver, sometimes cradling carbon, other times sighing it out, swayed by monsoon moods and microbial whims.

The nitrogen cycle faces similar turmoil, serving as nature's ingenious upcycler that reshapes air's abundant but inert nitrogen into nourishment for life. It launches with fixation, as bacteria in dirt or root nodules morph N_2 into ammonium; nitrification refines it to nitrate, ripe for plant absorption. As life fades, decay recycles ammonium, and denitrification loops it back skyward as N_2 or nitrous oxide. Hotter days and fiercer downpours rev these processes, heightening nitrogen's escape through washes or vapors in nitrification and denitrification (Balestrini et al. 2014: 462–464). This surges nitrous oxide—a potent warmer—billowing from the soil. Nitrogen dumped from blazes or human haze overloads woodlands, shattering their fragile poise (ibid 465).

Microbes, the quiet champions, pivot nimbly to these warmer, damper realms, reshaping soil's chemical makeup, freeing metals and nutrients that trickle into rivers, binding land and water in shared rhythms (Brady & Weil 2016: 430–432).

Ultimately, these upheavals reveal microbes as the vital bridge between climate and chemistry in the Himalayas, compelling us to decode these intertwined loops for wiser paths to adapt and stem the warming flow.

8. Research Gaps, Policy Implications and Future Directions

Even though climate change impacts in the Eastern Himalayas are now widely acknowledged, our understanding of the region's chemical and environmental processes remains surprisingly incomplete. A major challenge is the lack of long-term, fine-scale chemical data across different elevations. Measurements of atmospheric particles, soil properties, water chemistry, and trace metals are scattered in space and often interrupted in time. Because of this patchy record, it becomes difficult to identify clear trends or to confidently link observed changes to specific climate drivers (IPCC 2023: 68–70). The problem is especially acute in high-altitude landscapes, where research efforts are

limited by difficult terrain and harsh conditions, even though these areas are among the most sensitive to rising temperatures and changes in snow and ice.

Another important gap lies in how chemical data are used—or often not used—within climate and ecological models. While projections of temperature and precipitation over the Himalayas have improved in recent years, models rarely include detailed biogeochemical processes, contaminant transport, or microbial feedbacks (Krishnan et al. 2020: 223–225). This leaves major uncertainties about how water quality, soil fertility, and greenhouse gas emissions may evolve in the future. These uncertainties are further amplified in transboundary river basins such as the Brahmaputra, where limited data sharing between neighbouring countries prevents a coherent, basin-wide understanding of chemical dynamics and constrains coordinated management efforts (Xu et al. 2009: 526).

From a policy standpoint, environmental management in the Eastern Himalayas tends to remain reactive rather than preventive. Much of the focus is placed on responding to disasters after they occur, while longer-term chemical and ecological stressors receive less attention. Indicators such as nutrient enrichment, trace metal accumulation, and atmospheric deposition are rarely incorporated into climate adaptation plans or land-use policies (ibid. 527). Without stronger regulatory controls on air pollution, wildfire emissions, and unsustainable land-use practices, chemical pressures on these fragile mountain ecosystems are likely to intensify.

Looking ahead, meaningful progress will depend on more integrated and inclusive approaches to research and governance. Bridging environmental chemistry with climate science, ecology, and the social sciences can provide a more realistic picture of how these systems function and respond to change. Long-term, coordinated monitoring networks, open and shared data platforms, and the inclusion of indigenous and local knowledge can all play a vital role in strengthening regional understanding. Addressing these gaps—both scientific and institutional—is essential if effective, evidence-based strategies are to be developed for protecting the Eastern Himalayas in a rapidly warming world.

9. Conclusion

The Eastern Himalayas are changing in ways that are both profound and deeply unsettling. Climate change is reshaping this region at a pace that is increasingly difficult for ecosystems and communities to absorb, and throughout this chapter it has become clear that chemical processes lie at the heart of these transformations—often quietly, and too often overlooked. Rising temperatures, shifting rainfall patterns, and rapid changes in snow and ice are not simply altering the landscape; they are reworking the chemistry of the air, soils, and waters that sustain life across the mountains. These shifts unfold across multiple scales and are tightly linked, creating feedbacks between climate, chemistry, and ecological systems that are complex, cumulative, and still not fully understood (IPCC 2023: 71–73).

Changes in atmospheric chemistry are already being felt. Increasing aerosol loads, more frequent and intense wildfire emissions, and growing fluxes of greenhouse gases are reinforcing regional warming while steadily degrading air quality. At the same time, soils are undergoing subtle but consequential transformations. Processes such as acidification, nutrient loss, and the mobilisation of metals are weakening the foundations of terrestrial ecosystems and threatening their long-term stability (Brady & Weil 2016: 432–435). Rivers and streams carry the imprint of these changes downstream, where shifts in ionic balance, rising nutrient concentrations, and declining water quality place growing pressure on freshwater biodiversity and on the millions of people who depend on these waters for drinking, agriculture, and livelihoods (Bolch et al. 2019: 226–228). Beneath the surface, microbial communities are responding to warmer and wetter conditions by accelerating the cycling of carbon and nitrogen, further intensifying greenhouse gas emissions and reinforcing climate–chemistry feedbacks (Schuur et al. 2015: 62–64).

These chemical changes do not remain confined to the natural world. They translate directly into human experience. Declining soil fertility, stressed water resources, and polluted air disproportionately affect indigenous and marginalised communities whose lives are closely tied to mountain landscapes and seasonal rhythms (Xu et al. 2009: 526–528). In this context, indigenous knowledge is not an alternative to science but a vital

complement to it. When combined with systematic chemical and climatic observations, it offers grounded insights into environmental change and pathways for adaptation that are both locally meaningful and scientifically robust.

Ultimately, responding to climate change in the Eastern Himalayas demands more than improved climate projections or isolated conservation measures. It requires environmental chemistry to be fully woven into climate research, policy-making, and resource management. Long-term and coordinated monitoring, genuinely interdisciplinary research, and stronger cooperation across political boundaries are all essential steps. Without such integration, efforts to protect the region will remain fragmented. With it, there is still an opportunity to safeguard the ecological integrity of the Eastern Himalayas—and the well-being of the people who call these mountains home—in an era of rapid and irreversible change.

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2

Climate Change and Environmental Chemistry in the Eastern Himalayas: Impacts on Soil, Water Quality and Contaminant Dynamics

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ABSTRACT

The Eastern Himalayas are among the most climatically sensitive mountain systems in the world. Rapid warming, changing precipitation patterns, and increasing extreme weather events are altering soil chemistry, hydrological processes and environmental quality across Northeast India. This chapter examines the chemical mechanisms linking climate change with environmental dynamics, focusing on soil nutrient cycling, organic matter decomposition, trace-element mobility, water quality degradation, and contaminant transport. Attention is given particularly to the role of temperature-dependent biochemical reactions, microbial mineralization, redox transformations, and hydrological variability in controlling environmental change. Quantitative evidence from the Eastern Himalayan region, including soil acidity, arsenic contamination, rainfall variability, and warming trends, is incorporated to strengthen the discussion. The chapter also evaluates how inadequate waste-management systems interact with floods and intense rainfall to increase pollutant leaching into soil and water resources.

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Furthermore, it highlights the application of analytical techniques such as AAS, ICP–MS, HPLC, and GC in regional environmental monitoring programmes. Through the integration of climate science, chemistry, hydrology, and environmental management, the chapter emphasizes the need for interdisciplinary approaches to enhance ecosystem resilience and environmental sustainability in the Eastern Himalayas.

Keywords: *Climate Change, Soil Chemistry, Arsenic Contamination, Water Quality, Eastern Himalayas*

1. Introduction

The Eastern Himalayas constitute a globally important ecological region characterized by steep terrain, intense monsoonal rainfall, exceptional biodiversity, and complex environmental gradients (Sharma et al., 2019). Northeast India forms a significant part of this mountain system and supports millions of people through agriculture, forestry, fisheries, and freshwater resources (Mahanta & Singh, 2022). The region is increasingly experiencing the consequences of climate change, including rising temperatures, altered rainfall distribution, frequent floods, landslides, and drought-like conditions (IPCC, 2021; Mahanta & Singh, 2022). According to the Intergovernmental Panel on Climate Change, mountain regions are warming faster than many lowland environments (IPCC, 2021). Observational studies in Northeast India indicate increasing mean annual temperatures of approximately 0.1–0.3 °C per decade in several locations during recent decades (Mahanta & Singh, 2022). Simultaneously, rainfall has become more erratic, with a tendency toward short-duration, high-intensity precipitation events. These climatic changes affect not only physical landscapes but also the chemical processes that regulate soil fertility, water quality, nutrient cycling, and contaminant mobility (Lal, 2018; IPCC, 2021). Chemical sciences provide essential tools for understanding these environmental transformations. Soil chemistry, hydrochemistry, environmental analytical chemistry, and geochemistry collectively explain how climatic factors modify nutrient availability, carbon cycling, pollutant transport, and ecological health (Lal, 2018; Brady & Weil, 2017). Understanding these interactions is essential for developing effective adaptation and mitigation strategies in the Eastern Himalayas.

2. Climatic Sensitivity of the Eastern Himalayas

The Eastern Himalayas are particularly vulnerable because of their geological youth, fragile slopes, and dependence on monsoon-driven hydrological systems (Sharma et al., 2019). Changes in climate directly influence soil moisture, weathering rates, river discharge, groundwater recharge, and biogeochemical cycling (IPCC, 2021; Mahanta & Singh, 2022). The recent studies have reported increasing climatic variability across Northeast India. Higher temperatures accelerate chemical reaction rates and biological processes, while altered precipitation influences the transport of dissolved ions, nutrients, and contaminants (IPCC, 2021). The extreme rainfall events increase soil erosion and sediment transport, whereas prolonged dry periods reduce dilution capacity in rivers and groundwater systems (Sharma et al., 2019; Mahanta & Singh, 2022). Climate change interacts with anthropogenic pressures such as deforestation, urban expansion, mining, and intensive agriculture (UNEP, 2023). Together, these drivers alter the chemical balance of soils and aquatic environments, increasing environmental vulnerability and threatening ecosystem services.

3. Climate Change and Soil Chemical Processes

3.1 Soil Nutrient Availability and Fertility

Eastern Himalayan soils are generally acidic, with pH values commonly ranging between 4.5 and 6.5 in upland forest and agricultural areas (Brady & Weil, 2017). Soil acidity strongly influences nutrient availability and metal mobility (Brady & Weil, 2017). Climate change affects these soils through modifications in rainfall intensity, temperature, and microbial activity (Lal, 2018). Intense rainfall promotes nutrient leaching (Brady & Weil, 2017). Essential nutrients such as nitrate (NO_3^-), potassium (K^+), calcium (Ca^{2+}), and magnesium (Mg^{2+}) are transported downward beyond the root zone, reducing their availability to plants (Brady & Weil, 2017; Lal, 2018). In highly weathered acidic soils, nutrient losses can be particularly severe because of low cation-exchange capacity and strong runoff processes. Temperature increases further influence nutrient cycling by stimulating microbial metabolism (Lal, 2018). Soil microorganisms decompose organic residues more rapidly under warmer conditions, initially increasing nutrient

availability. However, accelerated mineralization is often accompanied by greater nutrient losses through volatilization, runoff, and denitrification (Lal, 2018). The nitrogen cycle illustrates these changes clearly. Organic nitrogen compounds are converted into ammonium through ammonification. Subsequently, nitrifying bacteria oxidize ammonium to nitrate. Under waterlogged conditions associated with intense rainfall, denitrifying microorganisms reduce nitrate to gaseous nitrogen species such as N2O and N2, leading to nutrient depletion and greenhouse-gas emissions (Lal, 2018).

3.2 Soil Organic Matter and Carbon Dynamics: Chemical Pathways

Soil organic matter plays a central role in nutrient storage, aggregate stability, and water retention (Brady & Weil, 2017). Climate-induced warming accelerates decomposition through several interconnected biochemical pathways (Lal, 2018; Tripathi et al., 2018). The primary process involves microbial oxidation of organic carbon. Complex organic compounds, including cellulose, hemicellulose, and lignin, are enzymatically broken into simpler molecules (Lal, 2018). These compounds are subsequently oxidized according to generalized reactions such as:

Organic carbon + O_2 → CO_2 + H2O + energy

Higher temperatures enhance enzyme activity and microbial respiration rates, increasing carbon dioxide emissions from soils (Lal, 2018; Tripathi et al., 2018). The result is a reduction in soil organic carbon stocks and a weakening of long-term carbon sequestration capacity (Lal, 2018). In addition to aerobic decomposition, anaerobic processes occur in periodically flooded soils and wetlands. Under oxygen-limited conditions, microorganisms utilize alternative electron acceptors, producing methane (CH_4) and carbon dioxide (Tripathi et al., 2018). Such processes are particularly relevant in flood-prone regions of Assam and low-lying Himalayan valleys. The accelerated decomposition of soil organic matter creates a positive climate feedback mechanism (IPCC, 2021; Lal, 2018). Increased greenhouse-gas emissions contribute to additional atmospheric warming, which in turn further stimulates decomposition rates.

3.3 Trace Elements, Redox Chemistry and Soil Toxicity

Climate variability significantly influences the mobility of trace elements through changes in redox potential, soil moisture, and pH (Kar & Garai, 2020). Periodic flooding followed by drying alters the chemical forms of metals and metalloids, affecting their solubility and bioavailability (Kar & Garai, 2020). Iron and manganese oxides are important sorbents for arsenic and other contaminants (Kar & Garai, 2020). During flooding, oxygen depletion leads to reductive dissolution of iron oxides, releasing previously adsorbed arsenic into soil solution and groundwater. A simplified reaction may be represented as:

Fe(III)-oxide + e− ⊚ Fe2+

As iron oxides dissolve, arsenic is mobilized into surrounding water systems. Groundwater arsenic concentrations exceeding the World Health Organization guideline value of 10 μg/L have been reported in parts of the Brahmaputra floodplain. Some local investigations have identified concentrations substantially above recommended limits, creating serious public-health concerns. Similarly, changing soil chemistry can increase the mobility of cadmium, lead, and manganese. Acidification and fluctuating moisture conditions enhance metal solubility, increasing the risk of plant uptake and ecological toxicity.

4. Hydrological Variability, Water Chemistry and Waste-Related Pollution

4.1 Climate-Induced Changes in Water Regimes

Hydrological systems in the Eastern Himalayas are strongly influenced by monsoon rainfall and mountain runoff (Mahanta & Singh, 2022). Climate change alters river discharge, groundwater recharge, evaporation rates, and seasonal water availability (IPCC, 2021; Mahanta & Singh, 2022). More intense rainfall events increase sediment transport and erosion, whereas extended dry periods reduce river flow and increase pollutant concentrations (Mahanta & Singh, 2022). Changes in hydrological pathways influence both the quantity and quality of water resources across the region.

4.2 Surface Water Quality Degradation

Surface-water quality is increasingly threatened by agricultural runoff, urban wastewater, industrial discharges, and mining

activities (Singh et al., 2006; UNEP, 2023). Climate change amplifies these pressures by altering contaminant transport mechanisms. Heavy rainfall events generate large volumes of runoff that transport sediments, nutrients, pesticides, and metals into rivers and wetlands (Singh et al., 2006). Nutrient enrichment promotes eutrophication, characterized by excessive algal growth, oxygen depletion, and ecosystem degradation (WHO, 2017). Several studies have identified elevated concentrations of iron, manganese, lead, chromium, and other contaminants in selected river systems across Northeast India (Singh et al., 2006). During low-flow periods, reduced dilution capacity may increase contaminant concentrations and ecological risk.

4.3 Groundwater Contamination and Arsenic Mobilization

Groundwater represents the principal drinking-water source for many communities in Northeast India (Mahanta & Singh, 2022). Climate variability affects groundwater quality by modifying recharge processes, water-table fluctuations, and subsurface geochemical reactions. Arsenic contamination in the Brahmaputra floodplain provides a well-documented example of climate-sensitive hydrogeochemistry (Kar & Garai, 2020). Flooding creates reducing conditions that favour microbial reduction of iron oxyhydroxides (Kar & Garai, 2020). Arsenic adsorbed onto these minerals is subsequently released into groundwater. Seasonal fluctuations in groundwater levels further enhance arsenic mobilization by repeatedly altering redox conditions. Consequently, climate change may intensify contamination risks in vulnerable floodplain aquifers (IPCC, 2021; Kar & Garai, 2020).

4.4 Waste Management, Flooding, and Pollutant Leaching

Waste management represents an important but often overlooked dimension of environmental dynamics in the Eastern Himalayas. Rapid urbanization has increased the generation of municipal solid waste, plastics, electronic waste, and untreated wastewater (UNEP, 2023). The interaction between climate change and inadequate waste infrastructure creates additional environmental risks. During severe floods, open dumping sites may become inundated, producing contaminated leachate rich in organic matter, nutrients, heavy metals, and potentially toxic compounds (UNEP, 2023). Floodwaters transport these pollutants into nearby soils, rivers, wetlands, and groundwater

systems (UNEP, 2023; Mahanta & Singh, 2022). Organic waste decomposition generates ammonium, nitrate, and dissolved organic carbon, while electronic and mixed wastes may release lead, cadmium, chromium, and other hazardous elements (UNEP, 2023). Intense rainfall enhances downward migration of contaminants through soils, increasing the likelihood of groundwater contamination. Therefore, waste management should be viewed as an integral component of climate adaptation. Improved landfill design, leachate collection systems, recycling programmes, and decentralized wastewater treatment can reduce climate-related pollution risks in fragile Himalayan environments.

5. Role of Chemical Sciences in Environmental Monitoring

Chemical sciences provide the foundation for detecting, quantifying, and understanding environmental change (Brady & Weil, 2017). Modern analytical methods allow researchers to evaluate pollution sources, monitor ecosystem health, and assess climate-related risks. Atomic Absorption Spectroscopy (AAS) has been widely employed in Northeast India for measuring arsenic, iron, manganese, lead, and cadmium concentrations in water and soil samples (Kar & Garai, 2020). Investigations of arsenic contamination in the Brahmaputra floodplain have frequently utilized AAS to quantify trace-metal concentrations and identify contamination hotspots. Inductively Coupled Plasma–Mass Spectrometry (ICP–MS) offers even greater sensitivity and has been used in regional hydrogeochemical studies to determine trace-element distributions in groundwater, river sediments, and agricultural soils (Kar & Garai, 2020). The technique enables simultaneous measurement of multiple elements at extremely low concentrations. High-Performance Liquid Chromatography (HPLC) has been applied to monitor pesticide residues and emerging organic contaminants in agricultural landscapes (UNEP, 2023). Because tea cultivation and intensive agriculture are economically important in parts of Northeast India, HPLC-based analyses help evaluate contamination risks associated with agrochemical use. Gas Chromatography (GC) and GC–Mass Spectrometry are valuable for identifying volatile and semi-volatile organic pollutants (UNEP, 2023). These techniques have been used to investigate hydrocarbon contamination, pesticide residues, and

organic pollutants transported through river systems. Beyond analytical measurements, chemical modelling contributes to environmental management. Geochemical models simulate contaminant transport, mineral dissolution, adsorption processes, and redox reactions under different climate scenarios (IPCC, 2021). Such approaches improve prediction of future environmental risks and support evidence-based policymaking.

6. Interdisciplinary Approaches and Community Participation

Addressing environmental challenges in the Eastern Himalayas requires integration across chemistry, hydrology, ecology, climate science, and social sciences (IPCC, 2021). Environmental systems are interconnected; therefore, effective solutions must consider both natural processes and human activities. Community participation is particularly important because indigenous and local communities possess extensive knowledge of environmental variability and resource management (Sharma et al., 2019). Traditional practices involving soil conservation, water harvesting, and forest stewardship often complement scientific adaptation strategies. Citizen-science initiatives, community-based monitoring programmes, and collaborative research partnerships can strengthen environmental governance. Combining analytical monitoring with local knowledge improves risk communication and enhances adaptive capacity (Sharma et al., 2019).

7. Conclusion

The Eastern Himalayas are experiencing profound environmental changes driven by climate variability and human activities. Rising temperatures, altered precipitation patterns, and extreme hydrological events influence soil chemistry, nutrient cycling, carbon dynamics, trace-element mobility, and water quality. The chemical mechanisms underlying these transformations include accelerated microbial decomposition, enhanced nutrient leaching, redox-driven contaminant mobilization and climate-sensitive hydrogeochemical processes. Arsenic contamination in the Brahmaputra floodplain illustrates how climate and chemistry interact to create environmental and public-health challenges. Climate change also magnifies the impacts of inadequate waste-management systems, particularly during

flooding events that promote pollutant leaching and contaminant transport. Consequently, sustainable waste management must be integrated into broader environmental planning. Analytical techniques such as AAS, ICP–MS, HPLC, and GC provide critical tools for monitoring environmental quality and supporting evidence-based decision-making. Strengthening interdisciplinary research, improving environmental monitoring networks, and promoting community participation will be essential for safeguarding ecosystem resilience and human well-being in the Eastern Himalayas.

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3

Tracking and Forecasting Change in Eastern Himalayan Rainfall

Pratikshya Borpujari[1]

ABSTRACT

Climate change is fundamentally altering water and weather patterns in the Eastern Himalayas, directly threatening the agricultural resilience and water security of Northeast India. This study analyzes five decades (1974–2024) of IMD historical rainfall data across Assam and Arunachal Pradesh. It begins by confirming that the annual average rainfall is significantly decreasing across the region. The analysis first employs the Mann-Kendall test and Sen's slope estimator to rigorously assess monotonic trends and spatial heterogeneity. Crucially, the Pettitt test identifies a definitive structural regime shift in 1994, marking a transition to a drier climate state. To build reliable future scenarios, the research develops and evaluates an ensemble of forecasting models, including classical ARIMA, SARIMA, and advanced Prophet algorithms, designed to optimally capture the complex seasonality and continuous trend components of the nonstationary time series.

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Rigorous diagnostic checking, including the ADF test and a Ljung-Box test, confirms the model successfully captured the complex seasonality and downward trend as white noise. Model performance, evaluated via RMSE and AIC, BIC scores, establishes the most accurate predictive framework for the region. These quantitative results, mapping localized vulnerability and providing critical multi-year forecasts, offer essential and actionable insights to support climate adaptation strategies, agricultural planning and water resource management in this vulnerable region.

Keywords: *Climate Change; Rainfall Trends; Time Series Forecasting; Northeast India; Water Resource Management.*

1. Introduction

Heavy rainfall poses a significant challenge in Assam, leading to artificial floods that adversely impact crop yields in the region. The annual occurrence of heavy rainfall-induced flooding in Assam results in lower agricultural productivity compared to other states. Rainfall plays a pivotal role in determining agricultural productivity throughout India. While moderate rainfall is favorable, excessive rainfall can be detrimental to agriculture. Extensive research has been conducted to predict rainfall patterns in India. The Indian Meteorological Department consistently provides valuable rainfall forecasts for the country, but the unique climatic conditions of Assam and Arunachal Pradesh can complicate rainfall predictions in these areas. Time series analysis has been a subject of interest among researchers in both academic and research institutions. Over the past decade, researchers have explored various statistical and machine learning methods to forecast rainfall, including Seasonal Auto Regressive Integrated Moving Average (SARIMA), Auto Regressive Integrated Moving Average (ARIMA), Auto Regressive Moving Average (ARMA), and Prophet. Among these methods, SARIMA has gained popularity as a technique widely adopted by researchers for rainfall time series forecasting. For instance, **Wang et al. (2013)** employed the SARIMA model to analyze rainfall time series in Shouguang City, China, while **Graham and Mishra (2017)** applied the ARIMA model for rainfall forecasting in the Allahabad region of India. Furthermore, other researchers used the ARMA model

for rainfall data forecasting in Colorado, USA. These examples highlight the prevalence of statistical methods in research. The ARMA model relies solely on time data, not considering other climatic variables such as temperature, pressure, and humidity.

This chapter investigates long-term rainfall dynamics in the Eastern Himalayas using five decades of gridded data from the India Meteorological Department. The study addresses two central questions:

1. Is rainfall in the region exhibiting a statistically significant long-term decline?
2. Can robust time series models generate reliable multi-year forecasts to support planning?

Using non-parametric trend detection methods, change-point analysis, and forecasting models such as ARIMA, SARIMA and Prophet; the chapter develops an applied statistical framework for climate diagnostics and predictive modeling. The findings provide actionable insights for climate adaptation, agricultural planning, and water resource management.

2. Study Area and Data Description

The study utilizes gridded rainfall data from IMD spanning approximately five decades (1974–2024). The dataset contains 693 spatial grid points covering Assam and Arunachal Pradesh. For our study purpose, we took the following LATITUDE (24, 29), LONGITUDE (89, 97).

Preprocessing involved:

- Seasonal aggregation from monthly values
- Verification of missing values
- Outlier diagnostics using interquartile range analysis
- Conversion into annual and seasonal time series per grid point
- Log transformation of data before model fitting

The resulting dataset enabled both spatial trend analysis and aggregated regional modeling.

3. Methodological Framework

Given the non-normal and potentially non-stationary nature of rainfall time series, a combination of non-parametric trend detection and parametric forecasting models was used.

3.1 Homogeneity Tests

The **Pettitt test** (Pettitt, 1979) was used to assess the homogeneity of the rainfall data by identifying potential change points in the time series. Under the null hypothesis, the annual values Y_i of the testing variables Y are iid and the series are considered as homogeneous. Meanwhile under alternative hypothesis, it assumes the series consisted of break in the mean and considered as inhomogeneous. This test is capable to detect the year where break occurs. Pettitt test makes it easier to identify the break in the middle of the series. Pettitt test does not need this assumption because it is a non-parametric rank test. (Ahmad and Deni, 2013).

The test statistic is:

$K = \max |U_t|$

where U_t is based on rank differences between observations before and after time t.

3.2 Mann–Kendall Trend Test

The rank-based nonparametric Mann–Kendall (MK) (Mann 1945; Kendall 1975) method is used as the base method of trend detection in this study to find statistically significant trends. In the MK test, the null hypothesis (H_0) is that there has been no trend in rainfall over time and the alternate hypothesis (H_1) is that there has been an increasing or decreasing trend in the series. Let the time series be denoted as:

$$X = \{x_1, x_2, \ldots, x_n\}$$

The MK statistic S is computed as:

Where:

$\mathrm{Sgn}(x_j - x_i)$ is:

1 if $(x_j - x_i) > 0$

0 if $(x_j - x_i) = 0$

-1 if $(x_j - x_i) < 0$

Positive value of standardized test statistic Z indicates an increasing trend in the rainfall time series, whereas negative Z values determine a negative trend.

If $|Z| > Z_{1-\alpha/2}$, (H_0) is rejected and a statistically significant trend exists in the time series.

The MK test is particularly appropriate for rainfall data because:

- It does not assume normality
- It is robust to outliers
- It handles missing values reasonably well

3.3 Sen's Slope Estimator

Sen's nonparametric method (Sen, 1968) which gives a robust estimation of time series trend was used to estimate the magnitude of trends in the rainfall time series data of Assam and Arunachal Pradesh. When change in time series is present but cannot be detected using statistical tests to a satisfactory level then Sen's slope estimation gives a better output (Radziejewski and Kundzewicz 2004). Shahid (2010) used the method to detect the magnitude of trends in rainfall time series of Bangladesh and also similar method was adopted for this study.

The slope between all pairs of observations is calculated as:

$Q_i =$

The median of all Q_i values gives the Sen's slope estimate.

This provides a robust measure of annual rainfall change (mm per year).

3.4 Change Point Analysis

Change point analysis determines whether structural breaks exist in the rainfall series.

Two possibilities are examined:

- Abrupt structural shift
- Gradual monotonic trend

3.5 Time Series Forecasting Models

3.5.1 ARIMA Model

Box and Jenkins (1976) advanced the Autoregressive Integrated Moving Average (ARIMA) model which is considered as a powerful and extensively used statistical tool to analyse and predict time series data. Main advantages of the model are that it can detect seasonal changes and consider serial correlation within the time series (Yurekli et al. 2007). In the ARIMA (p, d, q) model, p = autoregressive term, d = trend term, and q = moving average term.

Steps involved:

1. Stationarity testing using ADF
2. Differencing if required
3. ACF and PACF analysis
4. Parameter estimation
5. Residual diagnostics

All data were checked by Augmented Dickey Fuller (ADF) test with a null hypothesis (H0) of stationarity. The results confirmed that the differenced series has no unit root, which means the presence of stationarity.

Durbin-Watson Test was applied to check for serial correlation (autocorrelation), ensuring that error terms are independent. Ranging from 0 to 4, a value near 2 indicates no autocorrelation, while values closer to 0 suggest positive autocorrelation and values closer to 4 suggest negative autocorrelation.

At the end performing a Seasonal Decomposition is the best way to see why the model is struggling. It breaks the data into three distinct parts:

1. Trend: The long-term progression.
2. Seasonal: The repeating monthly cycle (Monsoon/Dry seasons).
3. Resid (Residual): The noise left over.

3.5.2 SARIMA Model

The Seasonal Autoregressive Integrated Moving Average (SARIMA) model is an algebraic statement that describes how a time series is statistically related to its own past. The seasonal ARIMA model incorporates both non-seasonal and seasonal factors in a multiplicative model given as;

$ARIMA(p,d,q) \times (P, D, Q)_s$

Where; p = non-seasonal AR order, d = non-seasonal differencing, q = non-seasonal MA order, P = seasonal AR order, D = seasonal differencing, Q = seasonal MA order, and S = time span of repeating seasonal pattern.

Box and Jenkins established a three-step modeling procedure: identification, estimation and diagnostic checking steps. The identification step is to tentatively choose one or more ARIMA/ SARIMA model(s) using the estimated ACF and PACF plots.

The diagnostic checking stage involves assessing the adequacy of the identified and fitted models through possible statistically significant test on the residuals to verify its consistency with the white noise process e.g. the Ljung-Box test. Finally, the best fitting model would be selected among other satisfactory, competing models e.g. the information criteria statistics based on the AIC or BIC rule of thumb and forecast is made with the model of best fit.

The Box-Cox transformation is a statistical technique that stabilizes variance and makes non-normal, skewed data more normally distributed by finding an optimal power parameter (λ). It requires strictly positive data.

Using Box-Cox transformation and subsequently differencing, monthly, weekly and daily monsoon rainfall time series were made stationary. The best SARIMA models were selected based on the autocorrelation function (ACF) and partial autocorrelation function (PACF), and the minimum values of Akaike Information Criterion and Bayesian Information Criterion.

3.5.3 Prophet Model

Though Prophet was built for business purposes, it works for observed hourly, daily, weekly, and monthly time series data that has strong seasonality. It predicts time series as a generalized additive model combining the trend function, seasonality function, holiday effects, and an error term as given in Equation below.

$Y(t) = g(t) + s(t) + h(t) + €_t$

Where:

- g(t) = trend component
- s(t) = seasonality
- h(t) = holiday effects (if applicable)
- €t = error term

As this study uses the monthly rainfall data as an input variable, therefore, holiday effect will be invalid here. FBP provides a decomposition regression model that is extendable and easy to use for time series forecasting with a wide range of tuneable parameters. It has functionality for cross-validation to measure forecasting errors and provision to include additional regressors and customize seasonality. Prophet can handle outliers without

any requirement for imputation or missing data, but the best way to handle outliers is to remove them. Prophet automatically detects changes in trends by selecting change points from the historical data

3.6.1 Model Evaluation Metrics

Two evaluation metrics are used:

Root Mean Square Error (RMSE):

Mean Absolute Error (MAE):

Lower values indicate better predictive performance.

3.6.2 Model Selection Criteria

AIC (Akaike Information Criterion):

Where:

- L = likelihood
- k = number of parameters

BIC (Bayesian Information Criterion):

Lower AIC, BIC indicates better model

4. Results

The present study focuses on the northeastern region of India covering Assam and Arunachal Pradesh, located between 24°–29° N latitude and 89°–97° E longitude. The region is characterized by a humid subtropical climate influenced by the southwest monsoon. Based on the analysis of historical rainfall data over the past five decades, the mean annual rainfall of the study region is estimated to be approximately 2458.67 mm, indicating a high precipitation regime typical of the northeastern Himalayan foothill region. This rainfall is unevenly distributed over the area and annual cycles.

Analysis of the long-term monthly rainfall distribution indicates that a significant portion of precipitation occurs during the monsoon months. Approximately 65.2% of the annual rainfall is received during June – September (Fig. 1), highlighting the strong dominance of the southwest monsoon over the study region.

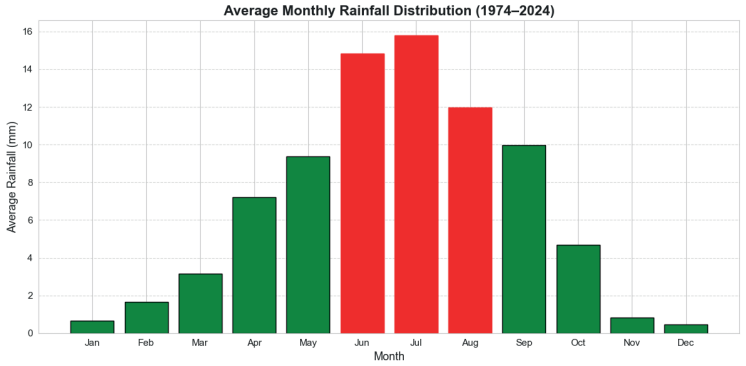


Fig. 1 Average monthly rainfall distribution for 50 decades

4.1 Change point analysis

Change point analysis was performed using the Mann–Whitney–Pettitt (MWP) and Standard Normal Homogeneity Test (SNHT). The results indicate a significant shift in rainfall around the late 1990s. The Pettitt test detected a change point in 1998, while the SNHT identified a change in 2000. Therefore, the most probable change point in the rainfall series is estimated to be around 1999, indicating a shift in precipitation patterns during this period.

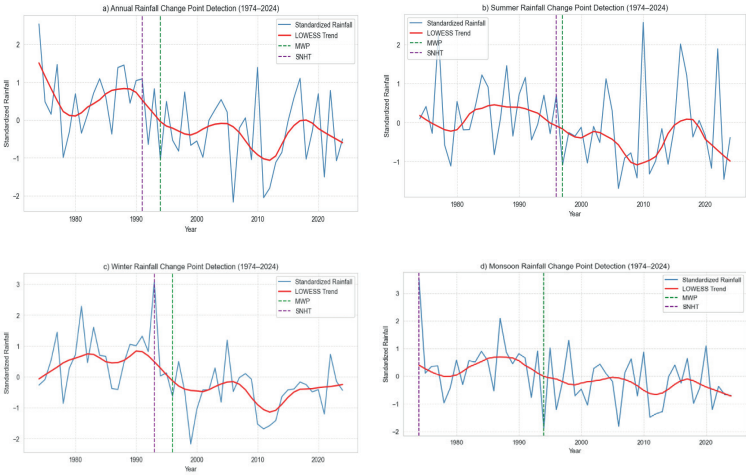


Fig 2: Standardized rainfall and LOWESS trend lines during 1974–2024 at Assam & Arunchal Pradesh

a) annual, b) summer, c) winter and d) monsoon

Rainfall decline is not spatially uniform.

- Winter (DJF): 173 out of 693 grid points show significant decline.
- Post-Monsoon (SON): 129 grid points show significant decline.

This spatial clustering identifies vulnerability hotspots rather than a homogeneous regional collapse.

4.2 Trend detection analysis

Before conducting trend analysis, homogeneity of the rainfall series was examined using the Pettitt test, The test successfully identified a significant change point at index 20, corresponding to the year 1994 (p = 0.0058).

The MK test confirms statistically significant decline in annual rainfall across multiple grid points. While the average monthly decline rate was 0.026 mm per year, the final analysis utilized annual total rainfall to better capture the cumulative hydro-climatic impact, which is -9.67 mm per year.

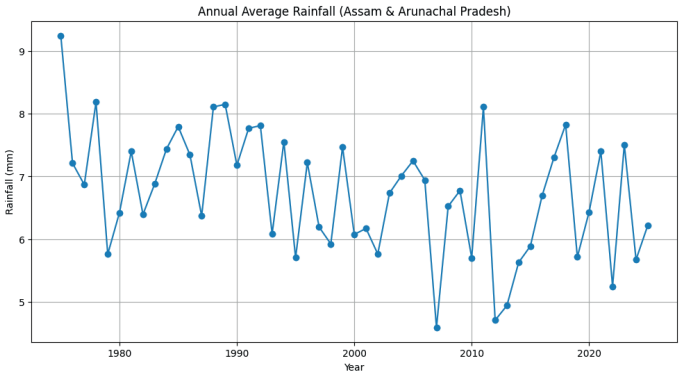


Fig 3 Annual average rainfall in parts of Arunchal and Assam

4.3 Forecasting Performance

The stationarity of the rainfall time series was examined using the ADF test. The results indicated that the original series is stationary.

The Durbin–Watson statistic was also calculated to assess autocorrelation in the residuals. The resulting value of 0.248

indicates strong positive serial correlation, confirming that the monthly precipitation is highly seasonal and non-random, justifies the application of an ARIMA or SARIMA approach.

Seasonal decomposition of the 1974-2024 rainfall series reveals a dominant and stable 12-month seasonal cycle, justifying the use of seasonal modeling approaches. The trend component displays non-linear behavior with a visible decline post-1994, corroborating the Pettitt and Mann-Kendall results. The presence of significant residuals during specific years indicates the occurrence of stochastic extreme climatic events that deviate from the established seasonal baseline

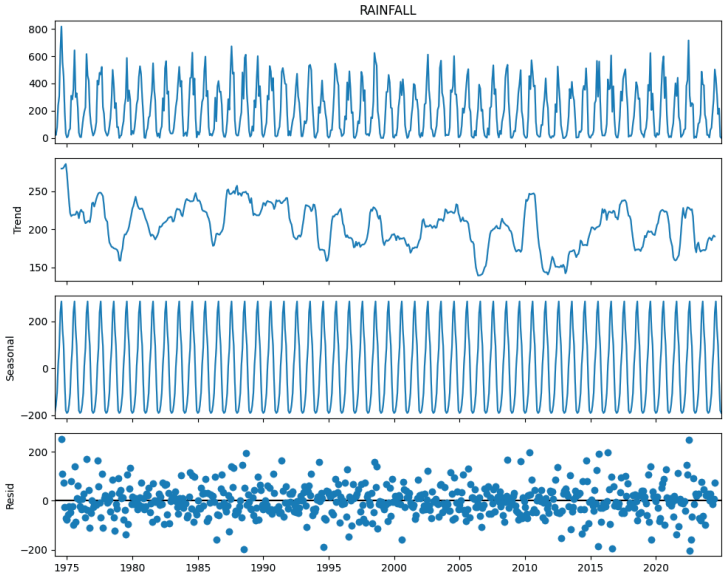


Fig 4 Seasonal Decomposition of rainfall over years

Diagnostic checking of the model residuals was performed using ACF and PACF plots. It indicates weak autocorrelation beyond the first lag, suggesting the presence of a low-order autoregressive component. The PACF shows a significant spike at lag 1 while subsequent lags fall within the confidence bounds, indicating an AR (1) structure.

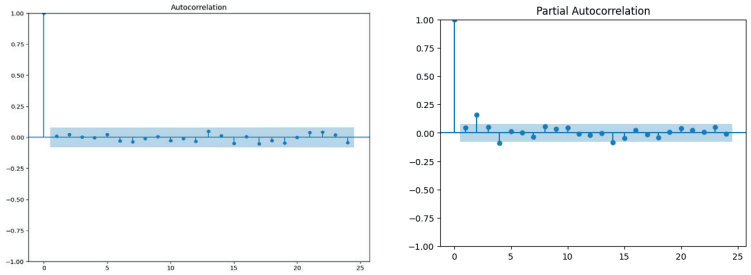


Fig 5: ACF & PACF plots for model selection

Based on the ACF and PACF diagnostics, ARIMA model was fitted. To account for SARIMA models were also fitted. The data was converted to log transformed

Model	AIC	BIC	RMSE
ARIMA (1,0,1)	1714.859	1732.446	1.635
ARIMA (1,1,1)	1821.047	1834.233	2.154
ARIMA (2,1,2)	1542.335	1564.311	1.123
SARIMA (1,1,1) (1,1,1,12)	1103.439	1125.314	0.571

The diagnostic adequacy of the SARIMA (1,1,1) (1,1,1,12) model was validated using the Ljung-Box Q-test. The test yielded a p-value of 0.875, significantly exceeding the 0.05 threshold for statistical significance. This indicates that the residuals are uncorrelated and behave as white noise, confirming that the model has successfully extracted the underlying trend and seasonal components from the log-transformed rainfall series. 5 years of monthly rainfall data have been predicted (Table 1)

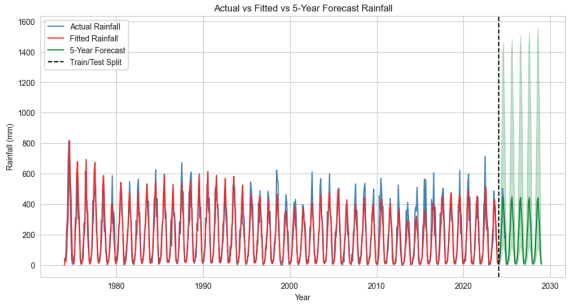


Fig 6: Actual vs Fitted vs 5 year forecast rainfall

To compare the performance of traditional statistical models with modern machine learning approaches, the Prophet forecasting model was also applied to the rainfall series. Prophet incorporates trend, seasonal components, and changepoint detection to capture non-linear patterns in time series data. But the RMSE score is better for SARIMA compared to Prophet.

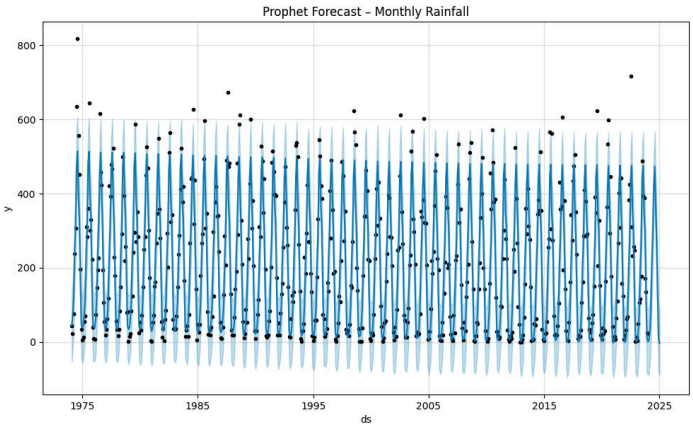


Fig 7 Prophet forecast of mainly rainfall

Table 1 5 years of monthly rainfall data prediction

Date	Predicted Rainfall (mm)	Lower CL (95%)	Upper CL (95%)
31-01-2024	14.734906	3.890553	49.625624
29-02-2024	34.144014	9.81227	113.231487
31-03-2024	78.794359	23.509155	258.786186
30-04-2024	186.390711	56.487811	609.82998
31-05-2024	270.023456	82.046595	883.487967
30-06-2024	419.55487	127.71428	1373.100825
31-07-2024	446.04334	135.660638	1461.365101
31-08-2024	339.727344	103.037778	1114.893912
30-09-2024	268.948536	81.329566	884.128103
31-10-2024	119.642897	35.75089	395.036898
30-11-2024	15.315133	3.96419	52.620749
31-12-2024	8.159981	1.783835	29.14017

31-01-2025	13.593627	3.413057	47.259963
28-02-2025	33.587096	9.443135	113.55058
31-03-2025	78.158612	22.869934	261.509561
30-04-2025	186.958867	55.60581	623.115014
31-05-2025	270.64847	80.705621	902.15562
30-06-2025	417.311967	124.658567	1391.54255
31-07-2025	445.275912	132.888412	1486.523723
31-08-2025	337.99338	100.573186	1130.366609
30-09-2025	269.658871	79.995151	903.451975
31-10-2025	119.046503	34.87862	400.664361
30-11-2025	15.174724	3.828064	53.187707
31-12-2025	8.012907	1.686891	29.23289
31-01-2026	13.530048	3.314849	47.929235
28-02-2026	33.463742	9.218772	115.232117
31-03-2026	77.884708	22.35813	265.408191
30-04-2026	186.336117	54.396538	632.520108
31-05-2026	269.745815	78.953951	915.818934
30-06-2026	415.87931	121.943701	1412.560499
31-07-2026	443.76907	129.993252	1509.150503
31-08-2026	336.833487	98.365606	1147.601308
30-09-2026	268.760675	78.237671	917.386679
31-10-2026	118.635988	34.094188	406.838749
30-11-2026	15.118617	3.721955	54.02166
31-12-2026	7.980737	1.627398	29.697157
31-01-2027	13.480474	3.219613	48.692743
28-02-2027	33.346524	8.992638	117.055289
31-03-2027	77.616518	21.839724	269.605588
30-04-2027	185.699583	53.16355	642.545978
31-05-2027	268.825837	77.169134	930.390414
30-06-2027	414.46221	119.191026	1435.120929
31-07-2027	442.257452	127.051894	1533.355819
31-08-2027	335.685102	96.1279	1166.088537
30-09-2027	267.84406	76.448206	932.231793

31-10-2027	118.229317	33.299317	413.458116
30-11-2027	15.063816	3.614696	54.918349
31-12-2027	7.950192	1.567541	30.199472
31-01-2028	13.431253	3.123088	49.510944
29-02-2028	33.229781	8.763376	119.007453
31-03-2028	77.349303	21.314218	274.098734
30-04-2028	185.065002	51.913814	653.274989
31-05-2028	267.908713	75.360439	945.981147
30-06-2028	413.050069	116.402238	1459.257174
31-07-2028	440.75084	124.07244	1559.246248
31-08-2028	334.540722	93.861708	1185.860097
30-09-2028	266.930274	74.6362	948.104149
31-10-2028	117.824061	32.494634	420.534911
30-11-2028	15.009215	3.506136	55.87688
31-12-2028	7.91977	1.506974	30.736383

5. Conclusion

This chapter provides a comprehensive statistical assessment of rainfall trends in the Eastern Himalayan region. The analysis of 50 years of monthly precipitation data reveals a statistically significant downward trajectory in rainfall. The Mann-Kendall trend test yielded a Sen's slope of -9.58 mm/year, indicating a persistent decline in the region's water availability over the last half-century. This trend is not merely a gradual shift; the Pettitt test identified a definitive structural break in 1994, marking a regime shift where the post-1994 period reflects a significantly drier climate state.

Before predictive modelling, the series was subjected to rigorous diagnostic testing. The AFD test produced a statistic of -6.15 ($p < 0.001$), confirming that the rainfall series is stationary and suitable for time-series modelling. Furthermore, a raw data Durbin-Watson statistic of 0.248 confirmed strong positive autocorrelation, scientifically justifying the need for an autoregressive model to capture the deep seasonal "memory" of the monsoon cycle.

To project future rainfall, multiple models were evaluated in log-transformed space to stabilize variance and ensure physical consistency.

- Model Selection: The SARIMA(1,1,1)(1,1,1,12) model emerged as the superior choice, achieving the optimal balance between parsimony and accuracy.
- Diagnostic Adequacy: The model achieved a Ljung-Box p-value of 0.875, proving that the residuals are white noise and that the model has successfully extracted all predictable patterns.
- Comparison with Machine Learning: While the Prophet model was evaluated, it was ultimately found inferior to SARIMA. Prophet's generalized Fourier seasonality lacked the precision of SARIMA's autocorrelation components, resulting in higher RMSE values on the millimeter scale.

Future studies might build upon the present study by including additional climatic parameters like temperature and evapotranspiration, applying spatial autoregressive models to account for geographical dependencies, applying CMIP climate projections to assess possible future changes, and exploring rainfall intensity and the distribution of extreme rainfall events. Such extensions would enhance understanding of the spatial and temporal dimensions of rainfall variability and its implications for climate risk. Given Northeast India's vulnerability and climatic diversity, such localized and data-driven approaches become especially significant to evolve effective climate adaptation and resilience strategies. Statistical modeling can thus be an important bridge between climate science and good governance. It can be utilized in converting observed and projected climate patterns into evidence-based information for planning, resource management, and adaptation interventions.

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4

Historical Trend and Variability of Rainfall in the Eastern Himalayan State of Sikkim

Dr. Yubaraj Sharma[1]

ABSTRACT

Sikkim, situated on the western side of the eastern Himalayas, receives among the highest annual rainfalls in India, and this chapter examines the long-term behaviour of rainfall in the state using 125 years (1901–2025) of daily gridded precipitation data across eleven spatial grids. A multi-scale statistical framework was applied to the IMD gridded dataset, incorporating descriptive statistics, monotonic trend estimation (Sen's slope with Mann–Kendall testing), structural change-point detection (PELT and Pettitt), seasonal decomposition, wavelet analysis, and selected extreme precipitation indices. Mean annual rainfall appears broadly stable over the studied time period. However, rainfall variability has increased in recent decades. This change is also accompanied by a relative weakening of monsoon-season contributions and a modest enhancement of pre-monsoon rainfall. Extreme precipitation indices do not indicate widespread or systematic intensification across the study grids.

Keywords: *Climate Change; Rainfall; Mann-Kendall; Sen's Slope; Change-Point; Wavelet; ETCCDI*

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1. Introduction

In India, the Southwest Monsoon dominates the annual rainfall cycle, delivering approximately 75% of rainfall between June and September (IMD, 2025a; Kulkarni & Koteswara Rao, 2023). This monsoon influence is further modulated by complex topography and orographic processes in mountainous terrains such as the Eastern Himalayas. Assessing how rainfall patterns have evolved over decadal to centennial scales is thus critical for understanding both regional hydroclimate and broader climate change impacts in the Eastern Himalayas. Rainfall in the Eastern Himalayan region is critical to water security, agricultural productivity, ecosystem functioning, and hazard regimes across much of South Asia, particularly through its control of river discharge in major Himalayan river systems (Kad & Ha, 2023; Kulkarni & Koteswara Rao, 2023; Swarnkar et al., 2021).

Within the Indian segment of the eastern Himalayas, the state of Sikkim occupies the westernmost part of this physiographic division, bounded by Nepal to the west and Bhutan to the east (Pradhan et al., 2010). It is among the high rainfall–receiving regions of India, with annual totals exceeding twice the all-India average (IMD, 2025a) [2]. Sikkim thus serves as a good study area for examining long-term rainfall variability in a complex mountainous environment.

Previous studies indicate increasing extreme precipitation in parts of the Himalayas, although trends are spatially heterogeneous due to strong topographic control and monsoon-driven variability. High-resolution grid-based assessments remain limited, particularly for smaller states such as Sikkim. While a number of studies have examined rainfall variability in the region, most are confined to smaller administrative or sub-regional units, cover relatively short time spans, or employ limited analytical methods (Chakma & Biswas, 2022; Das et al., 2017; Gupta et al., 2024; Sarkar et al., 2025; Sathyanathan et al., 2020; Wangsu & Shrivastava, 2024). This study extends this body of work by analyzing a longer temporal record across a wider area and fine spatial resolution. By integrating multi-scale aggregation, trend diagnostics, change-point detection, and variability assessment within a single framework, the present work provides a more comprehensive and internally consistent account of historical rainfall variability in Sikkim.

2 *cf.* Table 1 and accompanying discussion.

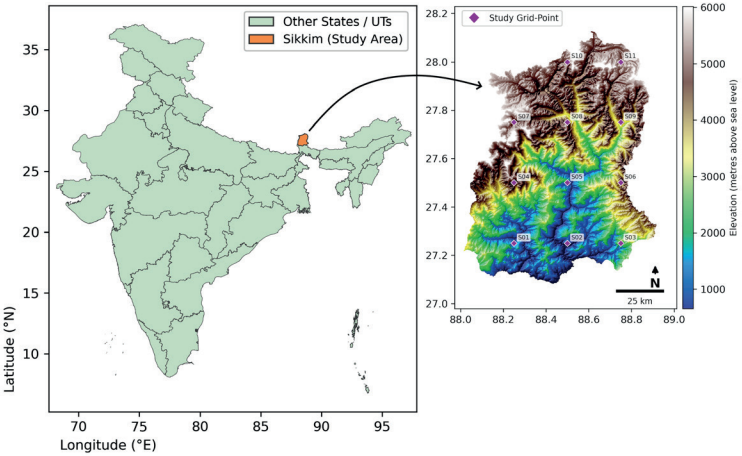


Figure 1: Location map of the study area showing Sikkim within India and the spatial distribution of rainfall grids (S01–S11 and SK) overlaid on a Digital Elevation Model (DEM).

2. Study Area

The administrative boundary of Sikkim provides a practical and policy-relevant spatial framework for analysis. While hydroclimatic processes transcend political borders, framing the study within a recognized region facilitates interpretation and communication of results. Figure 1 shows the location of the study area superimposed on a digital elevation model, highlighting its pronounced topographic heterogeneity.

3. Methodology

The study adopts a multi-scale, exploratory statistical framework to examine long-term rainfall behaviour across Sikkim. The approach integrates descriptive diagnostics, temporal trend analysis, structural change detection, variability assessment, seasonal decomposition, spectral analysis, and extreme-event metrics applied to high-resolution gridded rainfall data.

While formal detection–attribution analysis and climate model comparison are beyond the scope of this chapter, the methods are designed to identify statistically robust shifts in mean state, variability, periodicity, and extremes. The results should therefore be interpreted as evidence of evolving hydroclimatic

behaviour and potential climate-change signals, rather than definitive attribution to anthropogenic forcing. All processing and analysis were carried out using Python and relevant packages/libraries.

3.1 Data Source and Preparation

Out of the several precipitation datasets that were considered ‡, the IMD daily gridded rainfall dataset (Pai et al., 2014) was selected based on duration (1901–2025), resolution (0.25° × 0.25°) and ease of access. The dataset provides daily total rainfall (mm) for 135×129 grid points uniformly covering India. Eleven grid points were found to lie within the administrative boundary of Sikkim, designated with codes *S01–S11*, numbered from west-to-east and south-to-north. State-level rainfall was computed as the spatial mean across all grids (code *Sk*).

3.2 Descriptive Statistics

To establish the climatological baseline, descriptive statistics were computed for each of the grids and overall mean (*Sk)*. These descriptive statistics provide a quantitative summary of the central tendency, dispersion, and distributional shape of rainfall. Measures of central tendency included the mean annual rainfall total, mean daily rainfall, and median daily rainfall. Variability was assessed using variance and the interquartile range (IQR). Distributional shape was evaluated using skewness and excess (Fisher's) kurtosis.

3.3 Time-series

Time-series visualizations served as the prima facie analytical tool to examine temporal evolution in rainfall across the grids. Annual and decadal temporal scales were used to assess interannual variability, longer-term evolution, and possible regime shifts, consistent with standard climatological practice in hydroclimatic analysis (IPCC, 2023; Teegavarapu, 2019). To suppress high-frequency noise while retaining lower-frequency behaviour, annual aggregates were smoothed using a 365-day rolling/moving average. A 30-year climatological baseline (1901–1930) was adopted in accordance with WMO recommendations for defining climate normals (World Meteorological Organization, 2017). This provides an internally consistent historical reference period for anomaly comparison

suitable for assessment of long-term structural evolution. To reduce subjectivity inherent in visual interpretation, time-series diagnostics were complemented with formal non-parametric statistical tests to detect and quantify monotonic trends. The Mann–Kendall test was employed to assess the presence of monotonic trends in annual and seasonal rainfall (Hamed & Ramachandra Rao, 1998; Mann, 1945; Yue & Wang, 2004). The magnitude of change was estimated using the Theil–Sen (Sen's) slope estimator3, which provides a median-based rate of change (mm year^{-1}) and is resistant to the influence of extreme values (Sen, 1968).

3.4 Structural Change-Point Detection

To identify potential structural shifts in the rainfall time-series, two complementary change-point detection approaches were applied: PELT algorithm and Pettitt test. The Pruned Exact Linear Time (PELT) algorithm is a segmentation-based method that minimizes a penalized cost function and is computationally efficient for long time-series (Killick et al., 2012; Truong et al., 2020). This approach allows detection of multiple change points without pre-specifying their number. The non-parametric Pettitt test is based on rank statistics and detects a single most probable change point in the median of a time-series (Hussain et al., 2023; Pettitt, 1979). Because it does not assume normality, it is well suited to rainfall data, which are typically skewed and heavy-tailed.

3.5 Periodicity and Seasonal Structure

To investigate dominant periodicities and non-stationary periodic behaviour, a Continuous Wavelet Transform (CWT) was applied to annual mean rainfall using the complex Morlet wavelet. Periodicity is expressed in years, and the cone of influence (COI) was drawn to identify regions affected by edge effects. Intra-annual redistribution was examined by computing monthly means and aggregating rainfall into IMD-defined seasons: Winter (January–February), Pre-monsoon (March–May), Southwest Monsoon or simply Monsoon (June–September), and Post-monsoon or Retreating Monsoon

3 To test for autocorrelation in the time-series we used the Ljung–Box test (Ljung & Box, 1978) and used modified Mann–Kendall test (Hamed & Ramachandra Rao, 1998) if serial correlation was detected.

(October–December) (Met Glossary, n.d.). Heatmaps of month-wise rainfall were combined with seasonal time-series to simultaneously visualise month-specific anomalies and seasonal shifts.

3.6 Variability Diagnostics

To assess changes in rainfall dispersion independent of mean behaviour, monthly, annual and decadal standard deviations were computed for each grid to detect variability at different scales. Change-point detection was also applied to the standard deviation series to identify structural transitions in rainfall variability.

3.7 Extreme Climate Indices

To assess changes in the frequency, intensity, and persistence of extreme rainfall events in the study area, we analysed a reduced set of standard precipitation-based extreme climate indices that are recommended by the Expert Team on Climate Change Detection and Indices (ETCCDI). These have been widely adopted in regional and global climate assessments (Zhang et al., 2011). Out of the 11 precipitation-indices, 6 were selected based on their relevance to monsoon-dominated hydroclimatic regimes for parsimony and to avoid redundancy. The indices analysed include intensity-based measures: RX1day (annual maximum 1-day rainfall) and RX5day (annual maximum consecutive 5-day rainfall), which represent short-duration and multi-day extreme precipitation, respectively. Percentile-based measures: R95p (annual total rainfall from events exceeding the 95th percentile of wet-day rainfall), capturing very wet contributions relative to the local climatology. Frequency-based indices: R20mm (number of days with rainfall ≥ 20 mm) quantify the occurrence of heavy rainfall days. Persistence measures: Consecutive Dry Days (CDD), defined as the maximum number of successive days with rainfall < 1 mm, and Consecutive Wet Days (CWD), defined as the maximum number of successive days with rainfall ≥ 1 mm (ETCCDI, 2009).

These metrics collectively capture complementary dimensions of precipitation extremes—magnitude, frequency, and duration—which may respond differently to climatic forcing

and thus provide a more nuanced understanding than mean rainfall trends alone. For each index, annual time-series were constructed and subjected to Mann–Kendall trend testing and Sen's slope estimation to evaluate the presence and magnitude of monotonic change.

4. Results and Discussion

4.1 Descriptive Statistics

Table 1 summarizes the descriptive statistics for the 11 grid points (S01-S11) and the spatially averaged rainfall for the study area (Sk). The long-term mean annual rainfall for the state is estimated at 2826.5 mm, which is close to the value reported in the 2024 IMD report (IMD, 2025b) viz., 2799.2 mm [4]. Notably, Sikkim's annual rainfall is more than twice the all-India annual total (1206.6 mm for 2024 (IMD, 2025a)), highlighting the state's exceptionally humid hydroclimatic regime.

Table 1: Statistical summary of rainfall characteristics across the 11 spatial grids and the averaged representative grid for Sikkim (Sk). Table-cells are shaded based on their values ((lighter shades for lower values).

4 Note: In the report, IMD employs the 1971-2020 Long Period Average (LPA) as baseline, whereas the present study has adopted the 30-year (1901-1930) climatological normal recommended by WMO

Measures	S01	S02	S03	S04	S05	S06	S07	S08	S09	S10	S11	Sk
Mean of annual sum (mm year^{-1})	2596.8	2936.9	3365.8	2768.2	2769.0	3034.2	2735.8	2718.5	2824.1	2667.5	2675.1	2826.5
Mean (mm day^{-1})	7.11	8.04	9.22	7.58	7.58	8.31	7.49	7.44	7.73	7.30	7.32	7.74
Median (mm day^{-1})	0.64	0.73	0.66	0.89	0.95	1.21	1.02	0.91	1.02	0.92	0.73	0.88
Variance (mm^2)	207.5	262.3	341.5	222.5	218.9	236.4	199.5	210.9	215.7	194.6	208.2	228.9
IQR (mm day^{-1})	8.02	9.46	10.87	9.19	9.36	10.61	9.44	9.10	9.75	9.11	8.96	9.44
Skewness	4.55	4.63	4.29	4.63	4.73	4.02	4.20	4.62	4.45	4.30	4.59	4.46
Kurtosis	43.6	42.7	32.0	42.6	47.8	30.9	34.1	43.6	41.0	36.7	42.5	39.8

A clear spatial gradient is evident, with rainfall generally increasing eastward and southward, reflecting orographic enhancement. Thus, we find the highest accumulation at *S03*.

The observed statistics are indicative of the intrinsic intermittency and extremity of rainfall. Mean daily rainfall values (≈ 7–9 mm) substantially exceed the medians (≈ 0.6–1.2 mm), indicating that a limited number of intense rainfall events elevate the average. The large interquartile ranges (≈ 8–11 mm) and high variances (≈ 195–342 mm²) further indicate substantial intra-annual variability. Strong positive skewness (≈ 4–5) and very high kurtosis (≈ 31–48) across all grids confirm a highly right-skewed and extremely leptokurtic distribution, characteristic of monsoon-dominated rainfall regimes. These results collectively establish the broad characteristics of rainfall in Sikkim.

4.2 Mean Rainfall and Trends

Figure 2 presents the annual rainfall series (markers) for the 12 datasets (*S01-S11*, *Sk*) alongside a 365-day moving averages of daily rainfall, with decadal means superimposed to emphasize low-frequency variations. The 30-year climatological baseline (1901–1930) is overlaid in each subplot as a horizontal line for comparison.

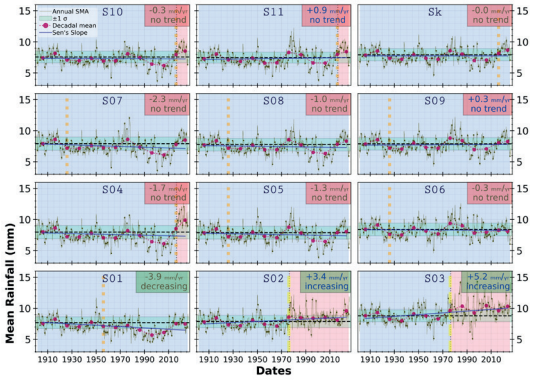


Figure 2: Annual rainfall time-series for the 11 grid points (S01–S11) and the state average (Sk), shown as 365-day moving averages of daily rainfall with decadal means superimposed. The 1901–1930 climatological baseline is indicated by a black horizontal dashed line with the shaded band showing ±1 standard deviation. Sen's slope estimates and Mann–Kendall test results are provided in inset panels, while vertical lines show Pettitt change-points: dashed yellow lines if statistically significant, otherwise dotted orange lines.

Monotonic trends (Sen's slope) and their statistical significance (Mann–Kendall test) are also given in figure 2[5]. Additionally, a line representing the Sen's slope is also plotted to facilitate visual comparison.

For most grids, estimated trends are statistically non-significant with small magnitudes (generally within ±1.5 mm year^{-1}) except for the southernmost grid. Two of those grids (e.g., *S02* and *S03*) exhibit statistically significant positive trends, whereas *S01* shows a significant negative trend.

While a relative decline in rainfall compared to the early baseline is observed from the mid-1980s to late 2010s in several grids, partial recovery is observed in recent years.

Change points detected using the PELT algorithm[6] and the Pettitt are shown in figure 2, while a separate jitter-plot of the change points is shown in figure 3. The results show that only two estimated Pettit change points (south-eastern grids) are statistically significant around the mid-1970s. No consistent breakpoints are observed across grids, suggesting that transitions, if present at all, are heterogeneous rather than state-wide.

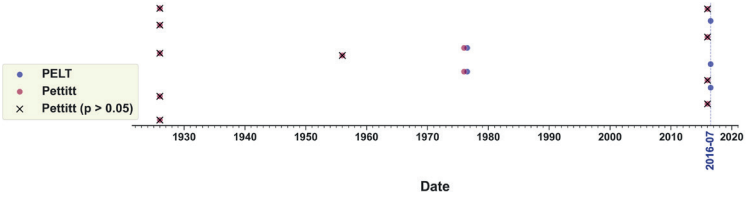


Figure 3: Jitter plot of change-points detected in annual rainfall series using the PELT algorithm and Pettitt test across the 12 datasets (S01–S11 and Sk).

4.3 Periodicity and Seasonality

Despite no long-term trend in annual rainfall in most of the grids, the smoothed decadal data does suggest the presence of oscillations. This is investigated using the continuous wavelet spectrum (figure 4).

5 The slope values in the textbox are in terms of annual sum (and not annual mean).

6 We set the PELT penalty value to 10 in this case.

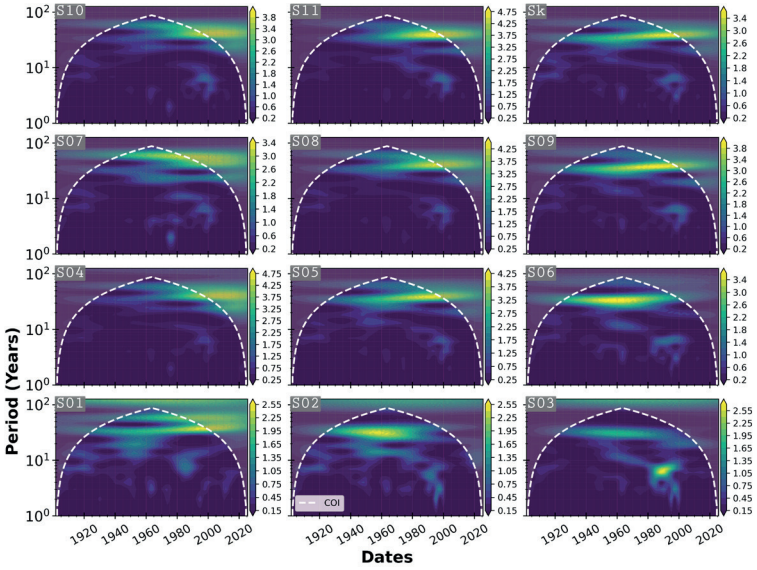


Figure 4: Continuous wavelet spectra of annual mean rainfall for the 12 datasets (S01–S11 and Sk). Shading denotes wavelet power, the vertical axis shows equivalent Fourier period (years, log scale), and the dashed white curve marks the COI.

The wavelet spectra reveal a prominent multi-decadal (~3–4 decade) band across most grids. Its strength varies over time and is broad indicating non-stationarity. Further, the spatial coherence of this band across the majority of grids suggests that this multi-decadal variability is not a localized phenomenon but rather indicative of regional climatic forcing. Additionally, we also find intermittent variability in the 4–6 years band temporally localized around the late-1990s to early-2000s in almost all the grids.

Seasonal decomposition into month-wise and season-wise variabilities are shown in figure 5. Care should be taken in interpreting the season-wise line curves, as they are intended only to illustrate the pattern of variation, and the y-axes are scaled to maximise the extent of the curve within the plot area[7].

7 That is, the y-axis limits are not consistent

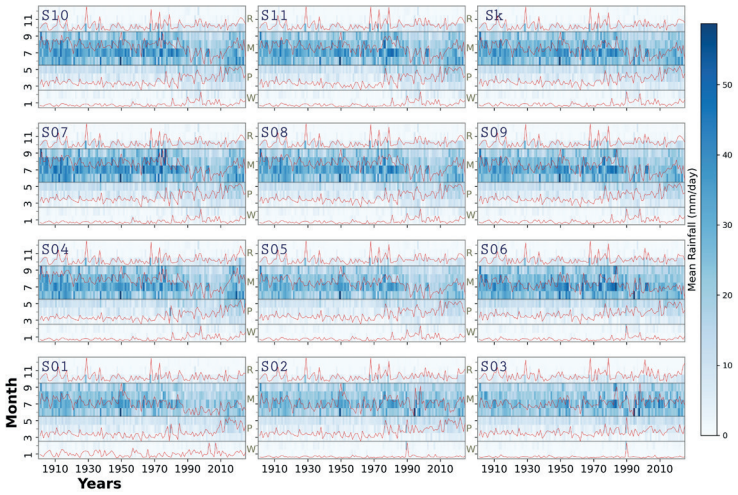


Figure 5: Month-wise and seasonal rainfall variability for the 12 datasets (S01–S11 and Sk). Shading represents monthly mean rainfall (mm day^{-1}) over the study period, while red line plots denote annual seasonal totals following IMD classification: Winter (W, January–February), Pre-monsoon (P, March–May), Southwest Monsoon (M, June–September), and Post-monsoon (R, October–December).

We can distinctly observe the dominance of the monsoon season (June–September), which contributes the largest fraction of annual rainfall across all grids. However, its relative weakening is observed in several grids, beginning in the early-1990s. It is accompanied by modest enhancement of pre-monsoon rainfall. Although annual totals remain broadly stable, the internal seasonal composition of rainfall appears to have shifted.

4.4 Variability and Structural Shifts

Figure 6 shows the temporal evolution of rainfall variability for each grid. Superposed on each subplot are monthly, annual and decadal line graphs. Due to different value ranges, the y-scale for the monthly values is placed on the right. Similar to the rainfall time-series, we have used 30-year average as the baseline.

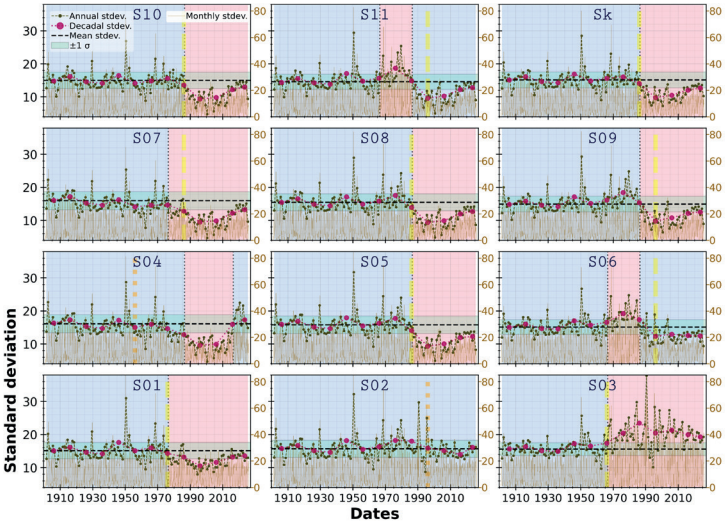


Figure 6: Temporal evolution of rainfall variability for the 12 datasets (S01–S11 and Sk), monthly, annual and decadal standard deviation of daily rainfall. The black horizontal dashed line indicates the mean standard deviation for the 1901–1930 climatological baseline, with the shaded band showing ±1 standard deviation. Vertical lines show Pettitt change-points: dashed yellow lines if statistically significant, otherwise dotted orange lines. Shaded regions denote segments identified by the PELT algorithm.

Standard deviation plots indicate increased dispersion of rainfall values in several grids after the late-1980s or early-1990s, most clearly observed in decadal variability, suggesting sustained rather than transient fluctuations.

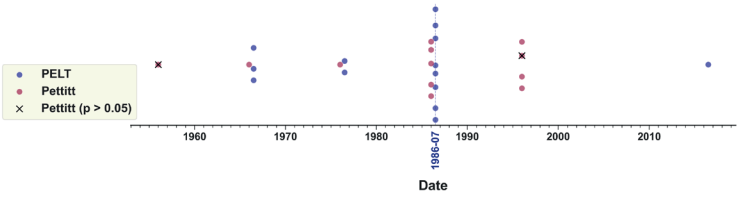


Figure 7: Jitter plot of change-points detected for annual standard deviation of daily rainfall using the PELT algorithm and Pettitt test across the 12 datasets (S01–S11 and Sk).

Change-point[8] clustering around the mid-1980s (figure 7) broadly coincides with the period of seasonal redistribution identified earlier (*cf.* figure 5). This co-occurrence supports the hypothesis of a transitional phase in rainfall variability in most of the grids around the 1980s.

4.5 Extreme Rainfall Behaviour

Results of analysis of the selected suite of extreme climate indices (ETCCDI) are given in figure 8, which is arranged to present a spatial pattern of the Sen's slope estimates for selected indices across the study grids. Trend significance was evaluated using the Mann–Kendall test, and statistically significant slopes are indicated by check marks (✓) adjacent to the values in the figure itself. Coloured markers indicate the magnitude of the Sen's slope.

We find no widespread intensification of short-duration extremes. Except for the south-eastern grid (*S03*), all other grids exhibit negative trends (with a few statistically non-significant) for the rainfall intensity-based indices RX1day and RX5day. A similar pattern is also observed for the two extreme precipitation indices: R20mm and R95p. With the exception of the south-eastern grids, most grids show index values that are negative or without trend, and are also largely statistically insignificant. Both CDD and CWD indices generally show negative or no trend, indicating reduced persistence of prolonged wet or dry spells and greater intermittency of rainfall events. Overall, the extreme indices suggest structural reorganisation rather than uniform amplification.

8 We set the PELT penalty value to 20 due to strong variability of the standard deviation time-series compared to the mean rainfall series.

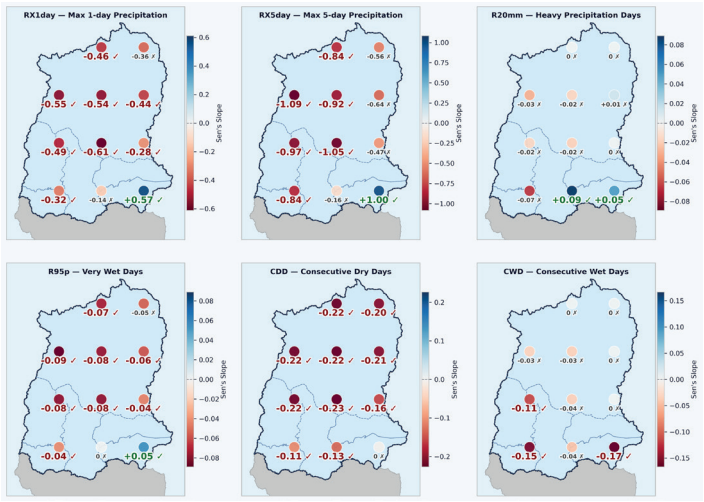


Figure 8: Spatial distribution of Sen's slope estimates for selected extreme precipitation indices across the 12 datasets (S01–S11 and Sk). Statistically significant trends (Mann–Kendall test, $p < 0.05$) are indicated within the figure. Grid codes are given in figure 1.

5. Conclusion

The present chapter examined long-term rainfall behaviour across Sikkim using a variety of tools. While mean annual totals were found to remain broadly stable relative to early 20th-century baselines, however, variability appears to have increased in several locations circa mid-1980s as well as noticeable seasonal redistribution of rainfall from monsoon to pre-monsoon. Wavelet spectra indicate non-stationary multi-decadal oscillations, while extreme indices reveal largely non-intensifying behaviour.

The overall picture is not one of simple increase or decrease in rainfall, but rather a structural shift, which can impact hydrological stability, slope processes, agriculture, and water-resource management in mountainous terrain.

Acknowledgements

I wish to acknowledge the support and patience of my major students for indulging my distracted attention during the preparation of this manuscript.

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5

Aliens in the Grasslands: Building Evidence and Replenishing Habitats in a Rhino Abode in Assam

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ABSTRACT

Biological invasions impinge on native biodiversity by modifying ecosystem functioning, which is considered a major threat. Pobitora Wildlife Sanctuary (PWLS) harbors the highest density of one-horned rhinos. We conducted a land use/cover change analysis using satellite imagery from 2000 to 2021 to understand the changes. We classified forest, grassland, wetland, and river and found that the grasslands are in spatial decline, and woodlands are increasing.

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A grid-based sampling was conducted in January-March of 2023 to record the presence of invasive alien plants (IAPs) following Nath et al. (2019). A total of 19 grids were sampled and found that around 94% were invaded by Ipomoea carnea. Following Sinha et al. (2022), we set up five experimental plots to test the efficacy of different interventions, such as manual uprooting of IAPs and debarking of woody plants. Post-removal of the IAPs, we collected data on the regeneration of native species. We found that the abundance of native grasses is on an increase, with a decreasing trend of Ipomoea invasion. It was also found that the rhinos tend to congregate in the grassland patches that are either devoid of or have sparse IAP presence. This study can facilitate reviving degraded grassland and will contribute to long-term conservation of rhinos.

Keywords: *Ipomoea Carnea, Pobitora Wildlife Sanctuary, Greater One-horned Rhinoceros, Grassland Restoration, Invasive Alien Plants*

1. Introduction

Biological invasion by alien plant species is widely recognized as one of the most serious threats to native biodiversity, often resulting in habitat degradation and adversely affecting habitat-specialist fauna, exacerbated by major global change drivers such as deforestation, population growth, alterations in land use and cover, rapid economic development, urbanization, habitat fragmentation, and climate change (Ihlow et al., 2016 11(6)). The biological invasion of alien species is the second greatest concern, behind habitat destruction, according to the Convention on Biological Diversity (CBD). Even the United Nations has declared the ongoing decade for ecosystem restoration. Species such as *Lantana camara*, *Prosopis juliflora*, *Chromolaena odorata*, and *Mikania micrantha* have reportedly doubled their range in hotspots like the Western Ghats, Himalayas, and Northeast floodplains (including Assam's grasslands), occupying ~15,000 km2 of natural habitat by displacing native grass species, which are vital for herbivores such as rhinos, elephants, and livestock.

In Assam, grassland ecosystems are increasingly being degraded by the spread of various invasive alien plants (Lahkar et al., 2011; Nath et al., 2019), which in turn reduce vital resources for native grassland-obligate species. Policies, administration, and

research on biological invasions are currently limited by the lack of trustworthy data on the distribution of invasive species and their primary drivers, notwithstanding the seriousness of these concerns (McGeoch et al., 2016). Furthermore, the accelerated reduction of grasslands resulting from encroachment by native woody species constitutes an escalating concern that requires urgent intervention, as these open grassy ecosystems sustain high densities of megafauna (e.g., Rhinoceros unicornis, Bubalus arnee), which may be jeopardized by the invasions (Jhala, Gopal, et al., 2021; Jhala, Qureshi, & Yadav, 2021).

Pobitora Wildlife Sanctuary (PWLS), located in the floodplains of the Brahmaputra River, supports the highest density of greater one-horned rhinoceroses (Rhinoceros unicornis) in the world, with estimates exceeding 90 individuals within just 38 km² of prime habitat. This remarkable concentration makes PWLS a critical stronghold for the species, which relies heavily on the sanctuary's expansive grasslands (Das et al, 2019 E-234-241). However, the grasslands that sustain this species are under significant threat from invasive alien plants (IAPs), such as *Ipomoea carnea*, *Parthenium hysterophorus, Mikania micrantha*, and *Chromolaena odorata*, native woody plant encroachment, and intense cattle grazing. Even rhino mortalities were reported, suspected to be linked to malnutrition arising from limited grass availability and competition with cattle.

Grassland ecosystems in Assam are entirely management-dependent, requiring both natural processes, such as flooding and human-led interventions like controlled burning and invasive species management. This project was conceptualised specifically to address the management needs of the sanctuary and ensure the long-term survival of rhinos and other dependent species.

2. Study Area

Pobitora Wildlife Sanctuary is located on the southern bank of the Brahmaputra in the Morigaon district, Assam, India. The WLS has an area of 38.85 km² and is located near Guwahati city. The habitat of the WLS is dominated by grasslands with small patches of woodland and marshes (Choudhury 2005: 82-88). The WLS came into existence in the year 1987; before that, it was a grazing reserve and in 1971 was redesignated as a reserve forest.

The sanctuary is situated on a low-lying flat land with a slight east-to-west slope, making it subject to annual flooding. The WLS receives an average rainfall of about 2000-3000 mm, with temperatures ranging from 8°C in winter to 37°C in summer.

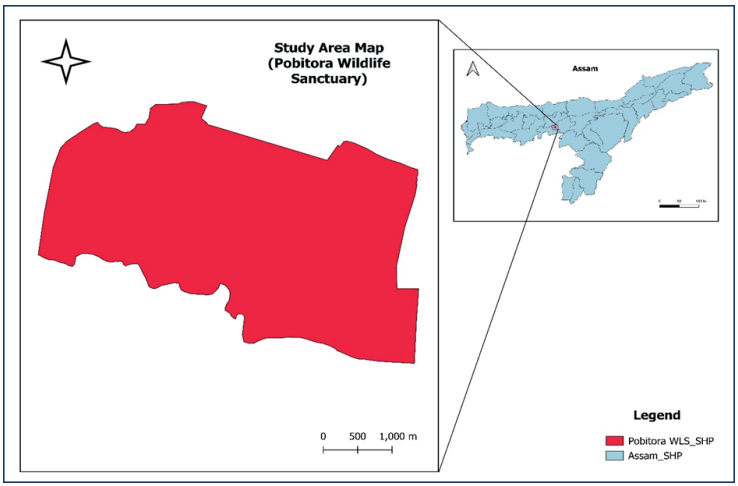


Figure 1: Study area map of Pobitora WLS

3. Methodology

Survey Design

The land use and land cover changes of Pobitara WLS and the neighboring areas were identified between 2000 and 2021 at five-year intervals using remotely sensed satellite imagery from sensors, including Landsat TM, Landsat 8, and Sentinel-2, and GIS methodologies. The different land use/cover classifications were classified using the supervised classification approach (Sarkar et al, 2024, 119-141). Based on a field study and the acquisition of a Region of Interest (ROI) from satellite data, the area was divided into seven main types.

The selected classes are as follows:

- Mixed moist deciduous forest
- Grassland
- Degraded area
- Wetland/Swamp
- River

- Sand
- Agriculture

To understand the current status and distribution of invasive alien plants and woody plant encroachment in Pobitora Wildlife Sanctuary. A systematic grid-based (1 x 1 km) survey in the grassland is conducted from January to March 2023 to understand the present distribution pattern of the IAPs and native woody plant encroachment. The whole of Pobitora WLS was divided into 19 grids, and a trained team surveyed the grids on foot, using vehicles, and from elephant back (wherever necessary) to quantify the extent of invasion by ocular estimation following Nath et al. (2019). Following Sinha et al. (2022), we also set up experimental plots to implement and validate the efficacy of various habitat management techniques such as cutting, cutting and burning, and manual uprooting for controlling IAPs. Additional experimental plots were set up to assess the efficacy of debarking as a management technique to control the spread of woody plants. Five such experimental plots were established in Haduk Highland (26°14.488'N, 92°3.030'E), Tuplung (26°14.018'N, 92°4.090'E), Simolu Tol (26°13.872'N, 92°4.167'E), Pipalati (26°13.928'N, 92°3.092'E), and Bakuljan (Fig. 2).

4. Results

There was a significant increase in the area covered by moist mixed deciduous forest and wetland from 2000 to 2021 in the main sanctuary area. The area cover of mixed moist deciduous forest increased from 301.5 ha (18.8%) in 2000 to 366.8 ha (22.9%) in 2021. Wetland cover also increased from 112.4 ha (7%) in 2000 to 132.5 ha (8.3%) in 2010, declined to 124.1 ha (7.8%) in 2015 and again increased in 2021 to 151.7 ha (9.5%). However, grasslands are in continuous decline from 1184.2 ha (74.0%) in 2000 to 1081.6 ha (67.6%) in 2021.

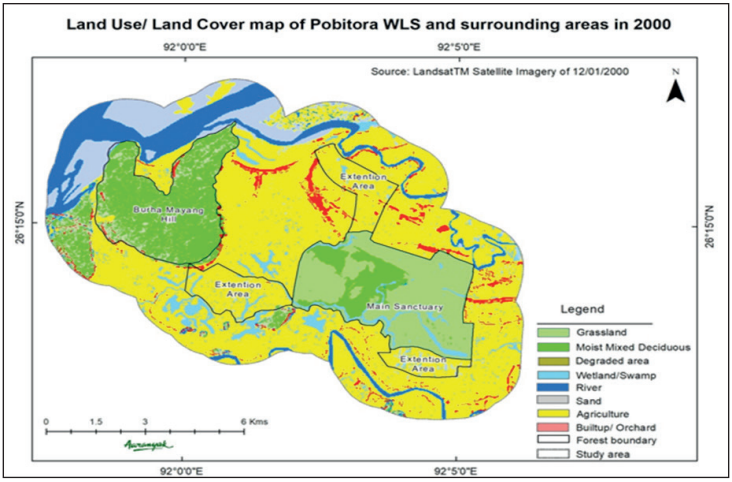


Fig 2. LULC map of Pobitora WLS and its surrounding areas, 2000

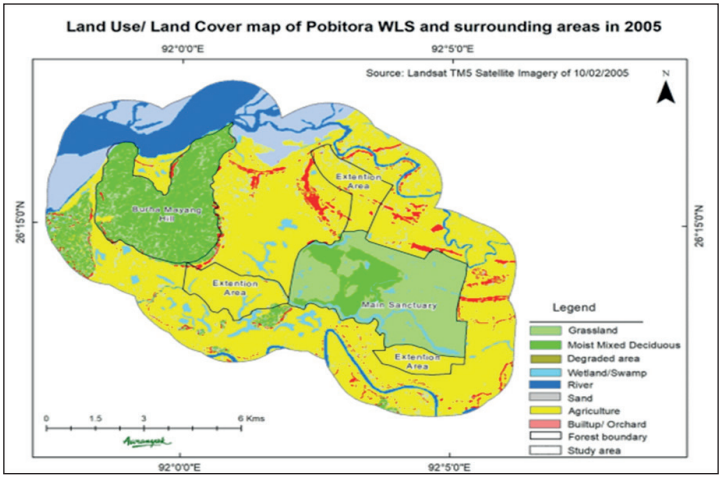


Fig 3. LULC map of Pobitora WLS and its surrounding areas, 2005

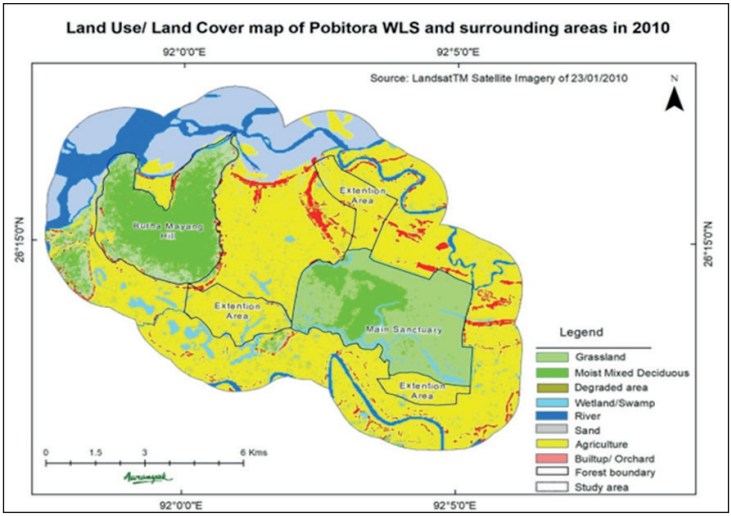


Fig 4. LULC map of Pobitora WLS and its surrounding areas, 2010

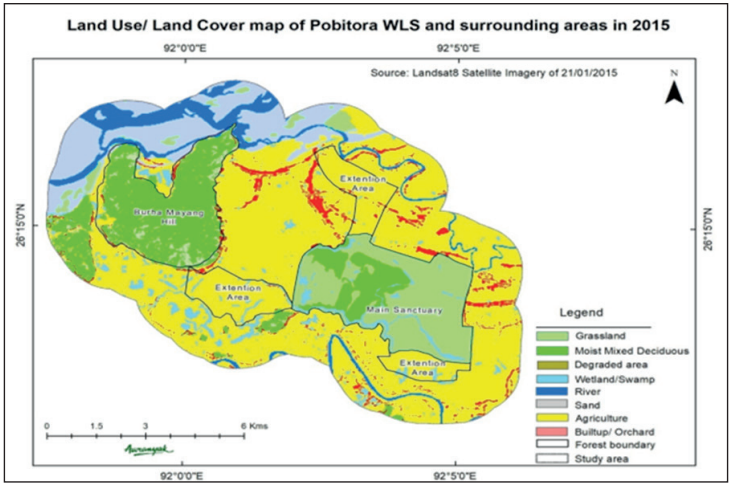


Fig 5. LULC map of Pobitora WLS and its surrounding areas, 2015

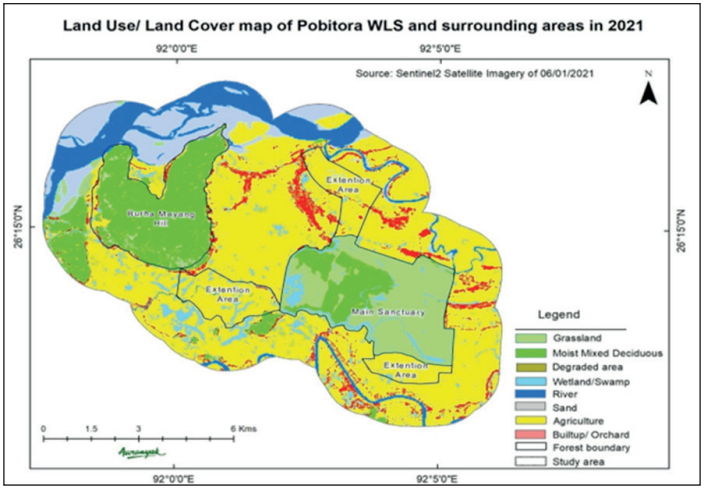


Fig. 6. LULC map of Pobitora WLS and its surrounding areas, 2021

Table 1: Land use land cover change in Pobitora WLS, 2000-2021

Sl. No	Classes	Area in hectares					Net Change area (2000-2021)
		Year 2000	Year 2005	Year 2010	Year 2015	Year 2021	
1	Moist-Mixed Deciduous forest	301.5	317.07	326.2	349.7	366.8	+65.3
2	Grassland	1184.2	1165.7	1140.0	1126.1	1081.6	-102.6
3	Wetland	112.4	117.3	132.5	124.1	151.7	+39.3
4	River	1.8	0.0	1.4	0.0	0.0	-0.4
Total		1600.0	1600.0	1600.0	1600.0	1600.0	

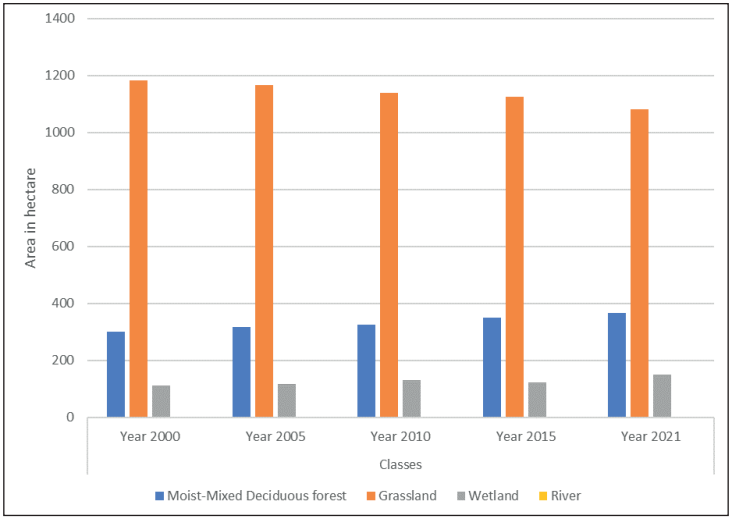


Fig 7. Land use/cover change within the main sanctuary area of Pobitara WLS (in hectares)

Table 2: Land use land cover change in Pobitora WLS, 2000-2021

Sl. No	Classes	Area in percentage (%)				
		Year 2000	Year 2005	Year 2010	Year 2015	Year 2021
1	Moist Mixed Deciduous forest	18.8	19.8	20.4	21.9	22.9
2	Grassland	74.0	72.9	71.3	70.4	67.6
3	Wetland	7.0	7.3	8.3	7.8	9.5
4	River	0.1	0.0	0.1	0.0	0.0
Total		100.0	100	100.0	100.0	100.0

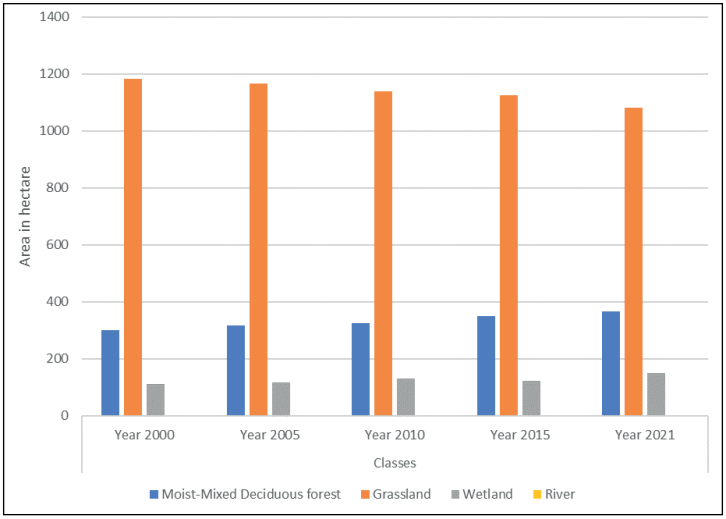


Fig 8. Land use/cover change within the main sanctuary area of Pobitara WLS (in Percentage)

IAPs were found in all 19 surveyed grids. *Ipomea carnea* was the most dominant IAP, being found in 18 grids, followed by *Parthenium hysterophorus*, which was found in 6 grids. *Mikania micrantha* and *Chromolaena odorata* were also found in 5 and 1 grids, respectively. In certain grids, approximately 70% area was covered by *Ipomoea carnea*.

Of all the techniques used to test the efficacy against IAPs, manual uprooting was found to be the most efficient against IAPs, and the debarking of woody plants also produced positive results. All five restoration plots were cleared of *Ipomea carnea* and woody plant saplings using the manual uprooting method. In Pepalati and Tuplung, debarking of 178 *Lagerostomia speciosa* (Azar) and 22 *Bombax ceiba* (Simul) was carried out, and the plants are either dead or showing signs of dying. In all five experimental plots, native grass species were observed after the uprooting process.

Following the results of the experimental plots, manual uprooting was applied in all the areas where IAPs were found. In 2023, 6.32 ha of area was cleared of IAPs; in 2024, the area cleared of IAPs increased to 167.8 ha. And in the year 2025, 102.9 ha were cleared of IAPs.

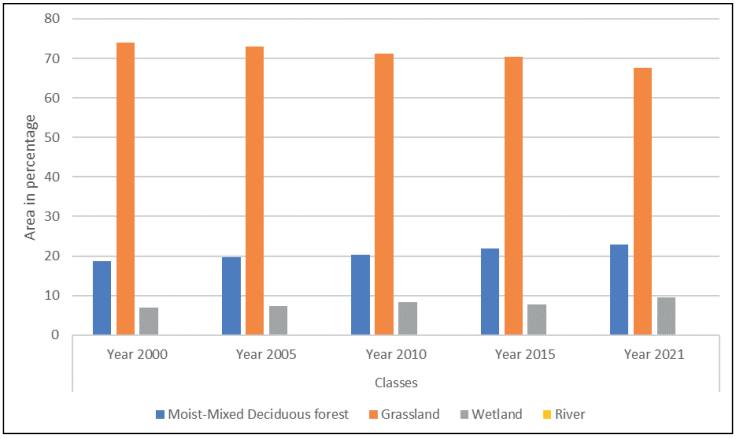


Fig 9. Amount of area cleared of IAPs each year in Pobitora WLS

5. Discussion and Conclusion

The present study provides integrated evidence that invasive alien plants (IAPs) and woody plant encroachment are jointly transforming the grassland ecosystems of Pobitora Wildlife Sanctuary (PWLS), with direct implications for the conservation of the greater one-horned rhinoceros. The long-term land use/land cover (LULC) analysis (2000–2021) indicates that although the proportional decline in grassland area appears modest, the consistent increase in moist mixed deciduous forest and reduction in degraded forest suggest a gradual but persistent process of woodland expansion into open grasslands. Such structural changes are ecologically significant in a management-dependent floodplain system like Pobitora, where even small losses or fragmentation of grasslands can disproportionately affect grazing megafauna.

The grid-based field survey revealed an alarming extent of biological invasion, with IAPs present in all 19 surveyed grids and *Ipomoea carnea* dominating nearly 94% of them. Recognised as one of the world's most invasive species, Ipomoea's ability to thrive on both land and wetland habitats provides it a competitive edge over other plant species in the floodplain landscape of Pobitora (Chari & Abbasi 2003, 2005). In several grids, Ipomoea alone covered up to 70% of the area, indicating advanced stages of invasion. This pattern is consistent with earlier

findings from Assam's grasslands, where invasive species such as *Chromolaena odorata* and *Mikania micrantha* have been shown to rapidly colonize disturbed and flood-influenced habitats (Lahkar et al., 2011; Nath et al., 2019). The dominance of *Ipomoea carnea* in PWLS highlights a shift in invasion dynamics, likely facilitated by altered hydrology, nutrient enrichment, grazing pressure, and the absence of regular large-scale management interventions.

Climate change can facilitate new biological invasions on regional and global scales through three pathways- by altering background environmental conditions, by increasing disturbance through extreme climatic events, and through human responses to climate change itself (Turbelin et al., 2021, 515-539). Disturbances such as floods, forest fires, droughts, and storms, which are accelerated by climate change, create ecological openings for IAPs, as they usually have broader climatic tolerance and a large geographic range (Qian and Ricklefs, 2006, 9:1293–1298). IAPs are further equipped with beneficial traits including short generation time, good dispersal ability, broad environmental tolerance and rapid growth, which allows them to colonize faster (Bradley et al., 2010, *25*(5), 310–318). These advantages of IAPs along with climatic changes, decrease resistance of native plants and can even shift native species distributions beyond their historical ranges, leading to negative consequences in these new habitats (Hellmann et al., 2008, 22: 534-543).

With climate change, shifting rainfall patterns and more erratic rainfall, along with unpredictable floods in the Brahmaputra basin, which is one of Asia's most flood-prone river systems, Ipomea and other non-native species get a repeated opportunity to spread to new habitats, as floods act as a vector linking adjacent habitats and carry propagules of non-native plants. In floodplain habitats like Pobitora WLS, this can accelerate their spread and invasion into nearby landscapes. This process of repeated flood disturbance, along with the rapid growth of Ipomoea, prevents the establishment of native grassland species and is further exacerbated by the encroachment of woody plants, slowly converting grasslands into forested land and reducing habitat and species diversity (Van Auken, 2009). This reduces the resistance of the ecosystem to future invasion, which can have significant implications for the conservation of rhino habitat.

Experimental restoration plots clearly demonstrated that active management can reverse invasion impacts. Among the tested interventions, manual uprooting emerged as the most effective technique for controlling IAPs, particularly *Ipomoea carnea*. Post-removal observations showed a marked increase in native grass regeneration and a concurrent decline in invasive cover, indicating that the soil seed bank of native grasses remains viable despite prolonged invasion. Similarly, debarking of native woody species such as *Lagerstroemia speciosa* and *Bombax ceiba* yielded positive results in limiting woody encroachment, supporting earlier suggestions that targeted mechanical interventions can help maintain open grassland structure in floodplain protected areas. However, a long-term management plan with regular monitoring and restoration integrated with tried and tested techniques such as manual uprooting & debarking would be essential to keep the grasslands invasive-free.

Importantly, field observations revealed that rhinoceroses preferentially used grassland patches with little or no invasive plant presence. This aligns with previous studies from Pobitora and other rhino habitats, which emphasize the dependence of Rhinoceros unicornis on short, palatable grasses and the avoidance of dense shrub or vine-dominated areas (Konwar et al., 2009; Das & Saikia, 2019). The congregation of rhinos in invasion-free patches underscores the functional loss of invaded grasslands as foraging habitats and provides strong ecological justification for prioritizing invasive species management as a core conservation strategy.

Taken together, the findings suggest that grassland degradation in PWLS is driven not by a single factor but by the interaction of land-use change in surrounding landscapes, invasive alien plants, woody plant encroachment, climate change and anthropogenic pressures such as cattle grazing. While policy-level recognition of invasive species as a major biodiversity threat exists (CBD; McGeoch et al. 2016), on-ground data-driven interventions remain limited. This study addresses that gap by combining spatial analysis, systematic field surveys, and experimental restoration to generate actionable evidence.

In conclusion, sustained, site-specific and adaptive management, particularly manual removal of IAPs and control of woody encroachment can effectively restore degraded grasslands in

Pobitora Wildlife Sanctuary. However, a monitoring system is required for early detection and rapid response for the long-term success of the grassland management. This system can reduce the ecological and economic cost of such management efforts, as established populations of IAPs are expensive to control (Venette et al. 2021). Periodic grid-based re-surveys supported by remote sensing and community participation should be incorporated in the management plan of the wildlife sanctuary, along with the replantation of native grass species immediately after IAP removal. Additionally, a thorough grazing management plan should be developed to regulate cattle grazing in and around Pobitora Wildlife Sanctuary, as the sanctuary faces severe grazing pressure, which can negatively affect grassland recovery and habitat quality. Such efforts are crucial not only for enhancing habitat quality but also for ensuring the long-term viability of the world's densest population of greater one-horned rhinoceroses. On the policy level, however, the implementation of such management plans faces constraints due to the absence of a dedicated national grassland policy and the government's forest-based bias in land use planning (Lahiri et al. 2023). The approach and outcomes of this study can serve as a practical framework for grassland restoration and invasive species management in other floodplain protected areas of Assam and the wider Brahmaputra landscape.

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6

Asian Elephant Conservation in Northeast India: Addressing Human-Elephant Conflict

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ABSTRACT

Northeast India, comprising Assam, Arunachal Pradesh, Meghalaya, Nagaland, Tripura, Manipur, Mizoram and its neighbouring region of North Bengal, supports approximately 10,139 wild Asian elephants according to the 2017 elephant census, making it one of the most significant conservation landscapes for the species. However, extensive deforestation, habitat degradation, and expanding human land use have led to the fragmentation of forests and disruption of traditional elephant corridors that once connected protected areas across the region. As a result, elephants are increasingly moving through human-dominated landscapes, leading to frequent and often adverse interactions with people. The conservation of Asian elephants, a species prioritized by the IUCN, is further challenged by the growing incidence of human-elephant conflict (HEC). In Assam alone, conflict-related incidents resulted in the loss of more than 1,400 human lives and 1,209 elephant deaths between 2000 and 2023, reflecting the scale of the challenge. Addressing HEC is inherently complex and requires coordinated, multi-stakeholder interventions that balance the needs of both people and wildlife. This paper examines how Aaranyak, a Northeast India-based conservation NGO, advances a multidimensional, community-oriented approach to elephant conservation. By integrating ecological and social science perspectives, the organization has implemented a range of interventions, including studies on elephant distribution and movement, corridor assessments, radio-collaring of elephants, identification of conflict-prone areas and evaluation of anthropogenic pressures influencing elephant presence. These efforts are complemented by community engagement in conflict management, implementation of locally appropriate mitigation measures, habitat restoration, and awareness-building initiatives aimed at fostering human-elephant coexistence. The scientific knowledge generated through these ecological studies provides a foundation for informed conservation planning, while community-centered conflict mitigation and long-term habitat management offer practical pathways for reducing HEC and ensuring the persistence of Asian elephant populations across the region.

Keywords: *Human-Elephant Conflict, Mitigation, Community-Centric, Conservation*

1. Introduction

The Asian elephant (*Elephas maximus*) is found in thirteen countries across Asia, with India supporting the largest population of the species (Fernando & Pastorini, 2011). Within India, wild elephants occur across twenty-three states, with southern and northeastern India harboring the most abundant populations (Perinchey, 2017). Northeast India, including North Bengal, supports approximately 10,139 wild elephants according to the 2017 elephant census, with Assam alone accounting for 5,719 individuals, followed by Meghalaya with 1,754. The region is therefore recognised as one of the most important conservation landscapes for Asian elephants.

Unlike many other elephant landscapes in India, eastern and northeastern India are characterised by relatively high ecological connectivity alongside rapid land-use transformation, making the region both a stronghold for elephants and one of the country's major human-elephant conflict (HEC) hotspots (Borah et al. 2021; Sangma et al. 2025). Rapid land-use change driven by agricultural expansion, mining, infrastructure development, urbanisation, and shifting cultivation has increasingly fragmented elephant habitats and disrupted traditional movement routes across the region (Rangarajan et al. 2010; Naha et al. 2019; Nad et al. 2022). Fragmentation and degradation of elephant corridors due to forest conversion and linear infrastructure further intensify conflict and complicate conservation and management responses (Menon et al. 2017; Guru & Das, 2021; Shahid et al. 2025).

As a result, elephants are increasingly forced to move through human-dominated landscapes, leading to frequent interactions with people and competition over space and resources. Human-elephant conflict manifests through crop depredation, property damage, injuries, and loss of life on both sides, while also influencing elephant ranging patterns, habitat use, and behaviour. The challenge is particularly acute in Assam, where conflict has resulted in substantial human and elephant mortality over the past decade. Beyond these direct impacts, persistent conflict can erode local tolerance towards elephants and undermine long-term conservation efforts.

Large-bodied herbivores such as elephants often experience high levels of conflict with humans, which can further exacerbate

conservation challenges for already threatened species (Seoraj-Pillay & Pillay 2017). Conserving elephants outside protected areas is therefore increasingly challenging in landscapes where human settlements, agriculture, and infrastructure overlap with elephant habitats (Treves & Karanth 2003).

Addressing HEC requires more than reactive conflict mitigation. Contemporary conservation approaches increasingly recognise coexistence as a more realistic and sustainable goal in shared landscapes, integrating ecological understanding with community participation, local knowledge systems and adaptive management (Gavin et al. 2018). Studies from Assam have highlighted the importance of understanding both the ecological and social dimensions of HEC, including local perceptions of elephants, community-based monitoring, and participatory mitigation approaches (Jadhav & Barua 2012; Zimmermann et al. 2009; Wilson et al. 2015; Vasudev et al. 2020; Keil 2022).

This chapter examines the efforts of the Elephant Research and Conservation Division (ERCD) at Aaranyak, a Northeast India-based conservation NGO. Guided by a human-elephant coexistence framework, these initiatives address both the ecological drivers and social dimensions of conflict to mitigate negative interactions and secure long-term conservation outcomes for Asian elephants.

2. Framework for Human-Elephant Coexistence

Human-elephant conflict is a multifaceted socio-ecological challenge that cannot be addressed through a single intervention. Effective conservation of Asian elephants in human-dominated landscapes requires approaches that simultaneously address ecological, social, and institutional dimensions of coexistence. Guided by the IUCN SSC Guidelines on Human-Wildlife Conflict and Coexistence, the Elephant Research and Conservation Division (ERCD) at Aaranyak, Guwahati has adopted an integrated framework since 2002. The framework is based on the premise that conservation outcomes are strengthened when ecological evidence informs management actions, communities are actively involved in decision-making and implementation, and interventions contribute to both elephant conservation and human well-being. Rather than treating conflict mitigation as an isolated activity, the framework recognises that reducing conflict requires addressing its underlying drivers, including

habitat degradation, loss of connectivity, limited ecological information, livelihood vulnerabilities, and inadequate awareness and preparedness among stakeholders.

Accordingly, the chapter is organised around five interconnected components of the coexistence framework:

1. **Ecological research and evidence generation** – to improve understanding of elephant distribution, habitat use, movement patterns, landscape connectivity, and the ecological drivers of conflict, thereby supporting science-based conservation planning.
2. **Habitat management and restoration—to** enhance habitat quality, restore degraded ecosystems, and maintain critical corridors that facilitate elephant movement and reduce pressure on human-dominated areas.
3. **Community-centered conflict mitigation—to** strengthen local capacity for conflict preparedness and response through participatory planning, community-managed mitigation tools, and collaborative engagement with government agencies.
4. **Livelihood diversification and community empowerment—to** improve the resilience of conflict-affected communities by promoting sustainable livelihood options that reduce vulnerability to elephant-induced losses and support local stewardship of conservation initiatives.
5. **Conservation outreach and awareness—to** foster understanding of elephant ecology, encourage behavioral change, strengthen stakeholder collaboration, and build long-term support for coexistence.

Together, these components represent a holistic approach to conservation that seeks not only to reduce human-elephant conflict but also to create conditions under which people and elephants can coexist within shared landscapes. The following sections illustrate how this framework has been applied across different landscapes in Northeast India and the lessons that emerge for elephant conservation and coexistence.

3. Study Area

The interventions described in this chapter were carried out in the transboundary Assam–Meghalaya landscape of Northeast

India, a globally recognized biodiversity hotspot important for the survival of the endangered Asian elephant. This landscape is a highly dynamic socio-ecological matrix of fragments of tropical moist deciduous and semi-evergreen forest interspersed with tea estates, riverine corridors along the Brahmaputra and its tributaries, and densely populated agricultural settlements. This contiguous belt is an important trans-state migratory corridor between the southern forested foothills of Meghalaya and the alluvial plains of Assam and is under severe anthropogenic pressure. Figure 1 below shows the geographical distribution of ERCD's targeted actions.

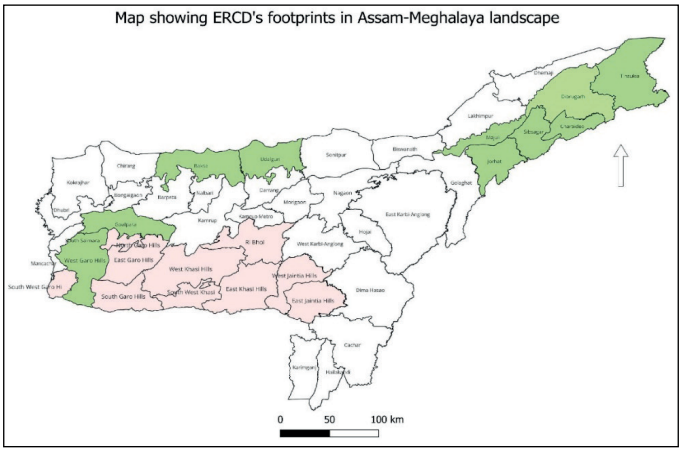


Fig. 1. Map showing ERCD's footprints in the Assam-Meghalaya landscape

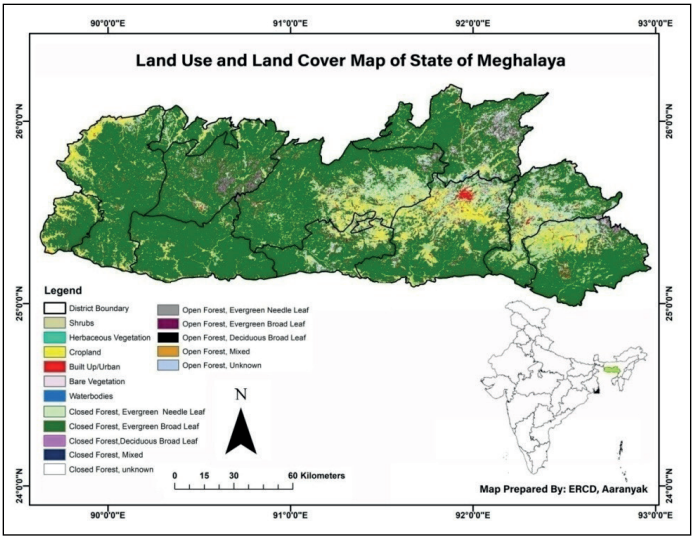
4. Interventions

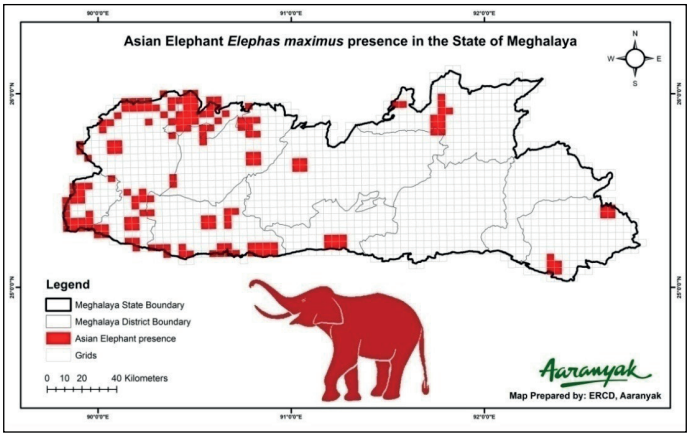
4.1. Ecological research and evidence generation

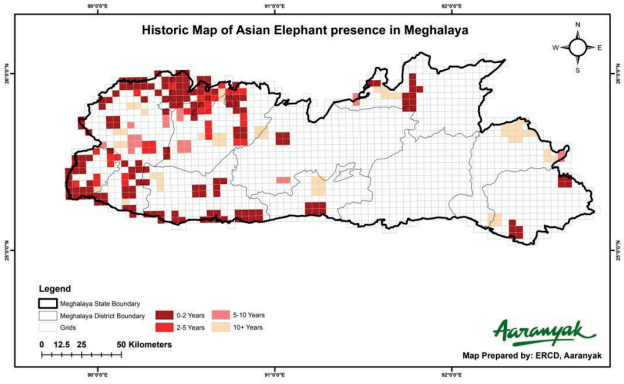
Generating robust ecological information is fundamental to understanding elephant movement patterns, habitat requirements, and the drivers of human-elephant conflict, thereby informing effective conservation planning.

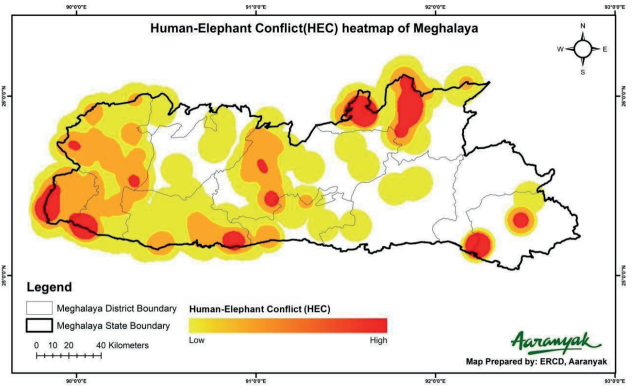
In Meghalaya, a critical component of the Northeast India–Indo-Burma biodiversity hotspot, conservation is particularly challenging as nearly 90% of elephant habitats occur outside the jurisdiction of the State Forest Department and are managed by communities, clans, or private landholders (WTI, 2010). To support evidence-based conservation, baseline information

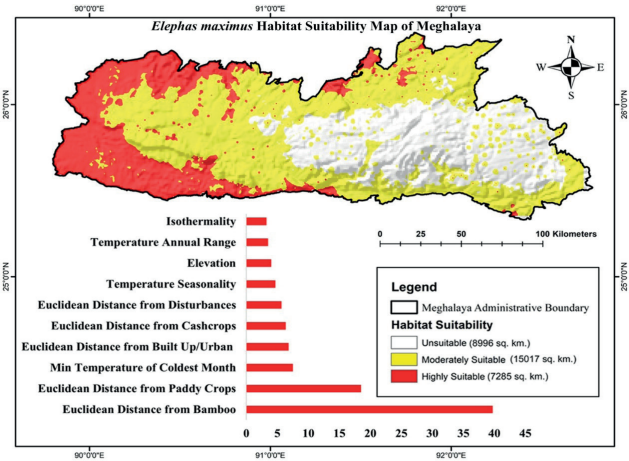
on elephant distribution, conflict hotspots, habitat suitability, and biological corridors was generated across the state. The study identified priority areas for conservation and conflict management, providing a scientific basis for safeguarding habitat connectivity, strengthening interstate and transboundary cooperation, and promoting multi-stakeholder conservation initiatives in a predominantly community-managed landscape.

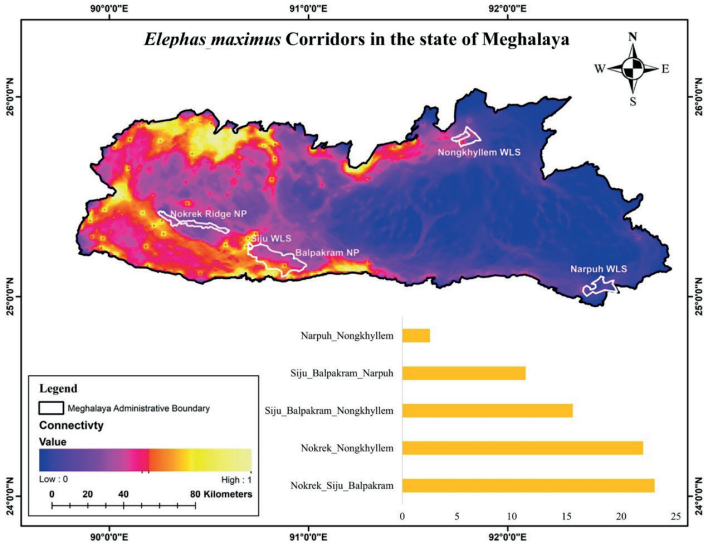





Historic Map of Asian Elephant presence in Meghalaya
N
W
E
S
Legend
Meghalaya State Boundary
Meghalaya District Boundary
Grids
0-2 Years
2-5 Years
5-10 Years
10+ Years
0 12.5 25 50 Kilometers
Aaranyak
Map Prepared by: ERCD, Aaranyak


Human-Elephant Conflict(HEC) heatmap of Meghalaya
N
W
E
S
Legend
Meghalaya District Boundary
Meghalaya State Boundary
0 10 20 40 Kilometers
Human-Elephant Conflict (HEC)
Low
High
Aaranyak
Map Prepared by: ERCD, Aaranyak


Elephas maximus Habitat Suitability Map of Meghalaya
N
W
E
S
0 25 50 100 Kilometers
Isothermality
Temperature Annual Range
Elevation
Temperature Seasonality
Euclidean Distance from Disturbances
Euclidean Distance from Cashcrops
Euclidean Distance from Built Up/Urban
Min Temperature of Coldest Month
Euclidean Distance from Paddy Crops
Euclidean Distance from Bamboo
0 5 10 15 20 25 30 35 40 45
Legend
Meghalaya Administrative Boundary
Habitat Suitability
Unsuitable (8996 sq. km.)
Moderately Suitable (15017 sq. km.)
Highly Suitable (7285 sq. km.)



In Western Assam, particularly the districts of Baksa and Tamulpur, experiences high levels of human-elephant conflict, especially during the paddy harvest season. However, limited information exists on elephant movements, habitat use, and ranging behaviour outside peak conflict periods. Understanding these ecological patterns is essential for identifying movement corridors, habitat requirements, and conflict drivers. To address this knowledge gap, two elephants, a tusker and an adult female were radio-collared in Baksa Forest Division during 2024–2025, marking the first radio-collaring initiative for wild elephants in Assam. The study is generating valuable information on seasonal movement patterns, habitat use, connectivity, and herd dynamics. These insights are expected to support evidence-based conservation planning, including habitat prioritisation, corridor management, and conflict risk assessment, thereby strengthening long-term strategies for human-elephant coexistence in the region.

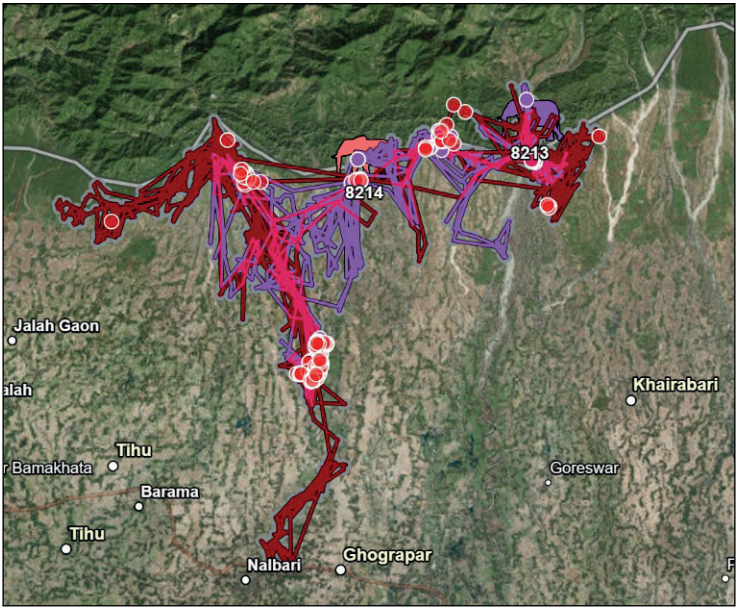


Figure 1: Signals received from the collared tusker and female, depicting their movement over the span of one year in Baksa and Tamulpur districts

4.2. Habitat management and restoration

Maintaining functional habitats is essential for the long-term conservation of Asian elephants and other wildlife in increasingly fragmented landscapes. Habitat restoration efforts in Manas National Park, Pobitora Wildlife Sanctuary, and Bhairabkunda Reserve Forest have focused on improving habitat quality, enhancing ecosystem resilience, and supporting biodiversity conservation.

In Manas and Pobitora, restoration interventions addressed habitat degradation caused by woody encroachment and invasive plant species through grassland management and ecological restoration measures. These efforts have helped restore native grassland structure and improve habitat conditions for elephants and other grassland-dependent species.

Similarly, habitat improvement initiatives in Bhairabkunda Reserve Forest have focused on ecological restoration through plantation programmes, nursery development, fire management,

and protection of restored areas. Implemented in collaboration with local communities and the Forest Department, these interventions have strengthened ecosystem resilience while promoting community participation in habitat conservation.

Together, these initiatives demonstrate the importance of habitat restoration in maintaining ecological integrity, supporting wildlife populations, and reducing long-term pressures on human-elephant shared landscapes.

4.3. Community-Centred Conflict Mitigation

Sustainable mitigation of human-elephant conflict requires the active participation of communities that share landscapes with elephants. Recognising this, Aaranyak has adopted a community-centred approach that strengthens local capacity, promotes stewardship, and enhances preparedness for conflict situations.

Community institutions such as Elephant Conservation Networks (ECNs), Rapid Response Units (RRUs), and Village Champions have been established across several conflict-prone districts of Assam. These groups function as local monitoring networks, facilitate early warning systems, support conflict response efforts, and serve as vital links between communities and conservation practitioners. Regular training programmes further strengthen their capacity in conflict management, elephant behaviour, and community outreach.

Capacity-building initiatives have also focused on improving disaster preparedness and community resilience through first-aid training, awareness programmes, and guidance on safe practices during elephant encounters, including access to compensation mechanisms.

In addition, a suite of community-based mitigation measures has been implemented, including solar-powered fencing, bio-fencing using citrus species, solar street lighting, watchtowers (*Tongshi*), and interventions to reduce elephant mortality from electrocution. A defining feature of these initiatives is their participatory nature, with communities actively involved in planning, implementation, maintenance, and monitoring. This shared ownership has enhanced the effectiveness and long-term sustainability of conflict mitigation efforts while fostering coexistence between people and elephants.

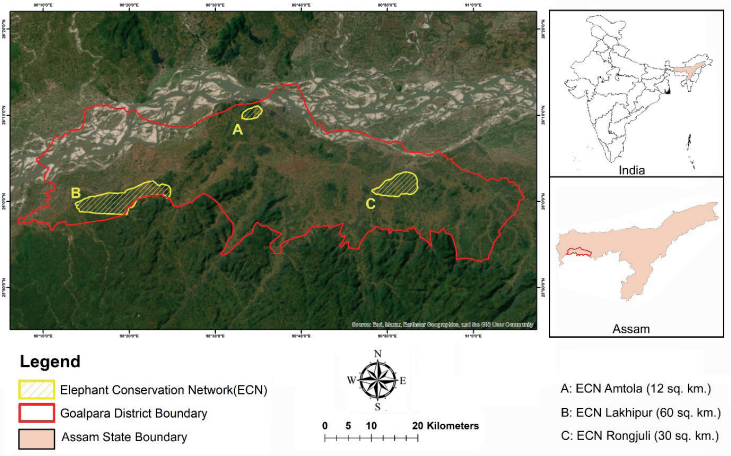


Figure 2: Elephant Conservation Networks of Goalpara district

4.4. Livelihood diversification and community empowerment

Many communities living in human-elephant conflict (HEC) prone areas depend primarily on paddy cultivation and are highly vulnerable to crop losses caused by elephants. To strengthen livelihood security and reduce dependence on conflict-prone agricultural practices, alternative livelihood options were promoted among farmers and women's self-help groups across Assam and Meghalaya.

These initiatives included support for beekeeping, fish rearing, weaving, poultry farming, mushroom cultivation, vermicomposting, and small-scale enterprises, coupled with capacity-building programmes conducted in collaboration with government agencies. Farmers were also encouraged to cultivate commercially viable and elephant-deterrent crops such as wild turmeric, citronella, lemongrass, chilli, and Assam lemon. Field trials demonstrated that these crops effectively deter elephant depredation while providing a sustainable source of income.

By diversifying income sources and promoting climate-resilient, wildlife-compatible livelihoods, these interventions have helped enhance community resilience, reduce economic vulnerability to HEC, and foster greater support for conservation initiatives.

4.5. Conservation Outreach and Awareness

Promoting long-term coexistence requires building awareness and fostering positive attitudes towards elephant conservation among local communities and future generations. To this end, a range of educational and outreach initiatives have been conducted across conflict-prone landscapes in Assam and Meghalaya.

School and community outreach programmes, including interactive sessions, documentary screenings, awareness campaigns, theatre-based communication, and the *Gajah Kotha* (Elephant Stories) initiative, have helped improve understanding of elephant ecology, the drivers of human-elephant conflict, and coexistence strategies. These efforts have been complemented by the development of locally relevant Information, Education and Communication (IEC) materials in Assamese, Bodo, and Garo languages.

Awareness has also been expanded through radio programmes, documentaries, and community storytelling platforms, enabling wider dissemination of conservation messages and local experiences. In addition, environmental observances such as World Elephant Day, World Environment Day, Wildlife Week, and other community events have provided opportunities to strengthen public engagement, celebrate local conservation efforts, and foster collaboration among stakeholders.

Together, these initiatives have contributed to improving conservation awareness, strengthening community participation, and building social support for human-elephant coexistence across the region.

5. Outcomes

The experiences presented in this chapter demonstrate that meaningful progress towards human-elephant coexistence is possible when scientific research, habitat management, community participation, and livelihood security are pursued together. Over the years, these integrated efforts have contributed to tangible benefits for both people and elephants across Northeast India.

A stronger scientific foundation for conservation has emerged through landscape-level studies on elephant distribution, habitat connectivity, and conflict hotspots, as well as Assam's

first radio-collaring initiative for wild elephants. These efforts have generated critical evidence to guide habitat management, corridor conservation, and conflict mitigation in some of the region's most challenging elephant landscapes.

On the ground, coexistence has been strengthened through extensive community engagement. More than 100,000 people have been reached through educational outreach, awareness campaigns, community meetings, radio programmes, and conservation events, helping foster greater understanding of elephant ecology and shared responsibility for conservation. Community institutions such as Elephant Conservation Networks (ECNs), Rapid Response Units (RRUs), and Village Champions have become important local partners in conflict preparedness and response, serving as early warning systems and strengthening grassroots stewardship.

Community-managed mitigation measures have further enhanced safety and security in conflict-prone landscapes. Low-cost solar-powered fencing systems, developed and maintained through strong community participation, now protect more than 200,000 people and over 400 elephants across Assam. In places such as Lakhipur in Goalpara district, where human-elephant conflict was once particularly severe, these collaborative approaches have demonstrated how partnerships between local communities, conservation organisations, and government agencies can significantly reduce risks to both people and wildlife.

The benefits of coexistence have also extended to livelihoods and well-being. More than 800 households affected by human-elephant conflict have received support through alternative livelihood initiatives, including elephant-deterrent crops, beekeeping, weaving, fish farming, mushroom cultivation, and other income-generating activities. These interventions have not only reduced economic vulnerability but have also provided communities with practical alternatives in areas where conventional agriculture is increasingly challenged by elephant depredation.

At the landscape level, approximately 170 hectares of wildlife habitat were restored during 2024–2025 across Manas National Park, Pobitora Wildlife Sanctuary, and Bhairabkunda Reserve Forest. These efforts have improved habitat quality and

ecosystem resilience, contributing to the long-term conservation of elephants and other wildlife species.

The programme has also strengthened institutional capacity by training personnel from multiple government agencies, including the Forest Department, Border Security Force (BSF), Sashastra Seema Bal (SSB), police, and local governance institutions, improving preparedness and coordinated responses to conflict situations. Beyond direct conservation outcomes, the initiative has supported the growth of young conservation professionals and community workers, while educational scholarships have helped children affected by conflict continue their studies.

Taken together, these achievements reflect more than a collection of conservation interventions. They illustrate how a coexistence-centred approach can simultaneously improve human well-being, strengthen community resilience, restore ecological systems, and secure a future for elephants in shared landscapes. In doing so, the initiative has contributed to multiple Sustainable Development Goals, demonstrating that biodiversity conservation and human development can advance hand in hand.

6. Conclusion: What does Northeast India teach us about living with elephants?

Several broader lessons emerge from these experiences.

First, ecological connectivity remains central to elephant conservation in Northeast India. Conservation efforts must therefore prioritise the protection and restoration of corridors and movement pathways that sustain elephant populations across fragmented and transboundary landscapes. Second, coexistence is most effective when ecological research, habitat management, conflict mitigation, livelihood interventions, and outreach are implemented as interconnected strategies rather than isolated activities. Third, community ownership is indispensable. Interventions that empower local communities and build local stewardship are more likely to be sustained over time and generate lasting conservation outcomes. Finally, the complexity of human-elephant conflict demands collaborative governance. Forest departments, local communities, civil society organisations, research institutions, district administrations, and neighbouring countries all have critical roles to play in securing a future for elephants in shared landscapes.

The experiences presented in this chapter demonstrate that coexistence is not a single intervention or outcome but an ongoing process that integrates ecological understanding, community resilience and institutional collaboration. Together, these elements provide a practical pathway for conserving Asian elephants while improving the well-being of people who share their landscapes.

Acknowledgement

We acknowledge the State Forest Departments of Assam and Meghalaya for constantly supporting our initiatives. Our heartfelt gratitude to our funding agencies, US Fish and Wildlife Services, British Asian Trust, Darwin Initiative and SBI Foundation, International Rhino Foundation for financially aiding us all these years. Our heartfelt gratitude to the District Administration of Udalguri, Baksa, Tamulpur, Goalpara, Kamrup, Majuli, Jorhat, Sivasagar, Dibrugarh, Tinsukia, Golaghat and Nagaon in Assam and Garo hills in Meghalaya in being a part of this voyage, and the villagers and conflict victims for being patient, resilient and most importantly for trusting us and our initiatives.

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7

Threats to Indigenous Fish Species and Conservation Strategies in the River and Wetland Systems of Assam

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ABSTRACT

Assam is endowed with numerous rivers and wetlands, which harbor a rich diversity of indigenous fish species. Presently, around 216 fish species are available in different water bodies, and 150 fish species possess ornamental importance in Assam. These indigenous fish species play a pivotal role in maintaining ecological balance and supporting local livelihoods and nutrition in the regions. In recent years, a rapid decline of these fish species has been observed due to various factors like habitat loss, pollution, overexploitation, total fishing, hydrological changes, climate change, urbanization, agricultural wastes, industrial runoff, and introduction of invasive species, among others. This study identifies the key factors that drive the dwindling of indigenous fish species and emphasizes the urgent need for conservation strategies such as creating artificial pocket habitat areas (PHAs), ranching programs, habitat restoration, ex situ breeding of threatened and endangered fish species, community participation, strict implementation of fisheries policy, establishment of community-managed fish sanctuaries, etc. in the rivers and wetlands of Assam.

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This paper highlights both anthropogenic and natural factors contributing to the decline of indigenous fish species, provides suggestive measures, and draws attention to the roles of both government and non-government agencies in these efforts.

Keywords: *Indigenous Fish Species, Conservation Strategies, Rivers, Wetlands, Assam*

1. Introduction

Fish play a very significant and crucial role, contributing to the survival and health of a majority of the world's population. Being a nutritional component, the fish meal serves as a source of energy in human life (Ojewola and Annah, 2006; Sutharshiny and Sivashanthini, 2011). In the recent global scenario, the demand for fish is enormously increasing day by day with the increase of the world's population. The global community is facing many difficulties, like financial, economic and climatic changes. But the world has finite natural resources, and on them, the growing population has to depend, which is projected to be 9 billion by 2050. Global food fish consumption increased significantly at a very high rate, and in per capita terms, food fish consumption rose from 9.0 kg in 1961 to 20.7 kg in 2022 (FAO, 2024). According to the 2023-2024 annual report of the Department of Fisheries, Govt. of Assam, 95% of people consume fish in Assam, and Assam's annual per capita fish consumption is 11.89 kg.

Assam is located between 89° 5′ and 96° 1′ east longitude and 24° 3′ and 27° 58′ north latitude, covering a total geographical area of 78,520 km², spreading over 35 districts with a total population of 3.6 crore. Assam has two main river systems, viz., the Brahmaputra River and the Barak River, covering a total water-spread area of 11,304.5 km. The Brahmaputra River system and the Barak River system are the main lifelines of Assam. The Brahmaputra River system originates in Tibet and moves to India through Arunachal Pradesh and flows into Assam, having a length of about 700 km. The Brahmaputra River system has many tributaries, and some of the notable tributaries are Subansiri, Dikrong, Jiabharali, Puthimari, Pagladiya, Manas, Beki, Aie, and Sankosh in the north, and Kopili, Kulsi, Dudhnoi, Jinjiran, Krishnai and Dhansiri are the main tributaries of the south bank. The Barak River is located in Barak Valley in

southern Assam, and the major tributaries of Barak are Jiri, Sonai, Katakhal, Chiri, Modhura and Dhaleswari.

Assam is endowed with vast fishery resources in the form of forest/oxbow lakes (No. 349) and derelict water bodies/swamps/ low-lying areas (No. 6022) covering a water spread area of 6102.90 ha and 83633.26 ha, respectively (Dept. of Fisheries, Govt. of Assam, Annual Report 2023-2024). The state has 447 registered and 1625 unregistered beel fisheries covering a water spread area of 30444.67 ha and 41398.70 ha, respectively, covering a total of 71843.50 ha (Dept. of Fisheries, Govt. of Assam, Annual Report 2023-2024). Some of the very important and major wetlands of Assam are Deepor *Beel*, Son *Beel*, Chaundubi Lake, Samaguri *Beel*, Urpad *Beel*, Morikalang *Beel*, Kapla *Beel*, etc. The state of Assam receives typical monsoon rainfall almost every year from the third week of June till the middle of September; the southwest monsoon rain prevails in the state. On average 180 cm of rainfall (about 80%) is received during this period, and the remaining 20% is in the form of occasional rains in other months of the year.

Coming to the recent ichthyofaunal diversity of Assam, it is enriched with around 216 fish species available in different water bodies and 150 fish species having ornamental value (Dept. of Fisheries, Govt. of Assam, Annual Report 2023-2024). The river system of Assam is well known for its rich indigenous fish species that contribute to the ecological balance and livelihoods of local communities. The fish species available in the river system play a significant role in different food webs, nutritional security, and also the habitat of different flora and fauna. It is also linked with the cultural and socioeconomic significance of indigenous fish species in supporting the livelihoods and traditional dietary practices of local communities. In the present scenario, the natural population of the fish species is declining day by day in various habitats due to shrinkage of its habitats and human interference, including the use of pesticides in the agricultural lands; besides, overfishing in particular is a serious threat to fish populations. However, dam construction for hydroelectric projects, siltation of its tributaries, drying of connected wetlands, conversion of wetlands to agricultural land, etc. are also great threats to the river system and wetlands in Assam.

2. Drivers of Fish Species Decline in the Rivers and Wetlands of Assam

The decline of indigenous fish species in Assam's rivers and wetlands is the result of multiple interacting environmental and anthropogenic factors. It is observed that rapid changes in freshwater ecosystems, coupled with increasing human interventions, have adversely affected fish habitats, breeding grounds, and the overall ecological balance. Understanding these underlying factors is essential for identifying the causes of biodiversity loss and formulating effective conservation strategies. The following discussion highlights the major factors contributing to the decline of indigenous fish species in Assam's river and wetland ecosystems.

The main factors contributing to the reduction of native fish species in Assam's rivers and wetlands are habitat degradation and rising human demands. The ecological conditions required for the survival and reproduction of native fish species have been drastically changed by the degradation, destruction, and fragmentation of aquatic ecosystems. Freshwater fish depend on wetlands, marshes, floodplain lakes, and interconnecting river channels for breeding, feeding, and nidification. However, habitat availability has decreased, and biological connection between nearby wetlands and rivers has been lost due to the filling of wetlands for developmental operations and the disturbance of natural water channels. Fish migration is restricted by this fragmentation, especially during breeding seasons, which has a negative impact on population recruitment and long-term survival.

Another major concern is the rapid eutrophication of rivers and wetlands caused by the excessive growth of aquatic vegetation. Dense vegetation reduces open-water areas, restricts fish movement, and lowers dissolved oxygen levels, thereby creating unfavorable conditions for many indigenous fish species. The proliferation of invasive aquatic plants, particularly water hyacinth (*Eichhornia crassipes*), further aggravates this problem by forming thick mats on the water surface. These mats obstruct sunlight penetration, reduce oxygen exchange, impede water circulation and interfere with feeding, breeding, and migration, ultimately lowering fish productivity and biodiversity.

Water pollution has also become a significant threat to freshwater ecosystems in Assam. Agricultural runoff carrying chemical fertilizers and pesticides, along with untreated industrial effluents and domestic waste, contaminates rivers and wetlands, leading to the deterioration of water quality. Such pollutants alter the physical and chemical properties of aquatic ecosystems, affect fish health, reduce reproductive success, and increase mortality among sensitive indigenous species. The cumulative effects of pollution are particularly severe in water bodies located near agricultural and urban areas, where continuous discharge of contaminants degrades aquatic habitats.

The decline of fish habitats has been accelerated by the conversion of wetlands into agricultural land. Many wetlands in Assam have been reclaimed as a result of increased population pressure and the rising demand for arable land. The availability of suitable habitats for native fish species significantly decreases as wetlands are smaller and fewer in number. The loss of wetlands interrupts the natural life cycle of many fish species and contributes to decreased fish populations because they serve as crucial breeding and rearing grounds. Another significant issue contributing to the loss of native fish resources is unsustainable fishing methods. Fish populations cannot naturally replenish due to indiscriminate fishing throughout the year, especially during spawning seasons. Fish stocks are progressively reduced as brood fish, juveniles and immature individuals are captured. The overexploitation of already endangered species has increased in many places due to increased fishing pressure brought on by reliance on fishing for a living.

Fish diversity in Assam has also been impacted by hydrological changes brought on by human activity and climate variability. Seasonal drying of rivers and wetlands due to irregular and decreased rainfall has impaired hydrological connectivity between nearby water bodies and reduced water availability. Fish movement, spawning possibilities, and access to food environments are all restricted by these changes. Additionally, the natural flow regime of rivers has been changed by the installation of hydropower dams and other water-control infrastructure in mountainous areas upstream. The availability of shallow inundated habitats, which many native fish species need for successful reproduction is sometimes diminished by fluctuations in water levels, particularly during the mating

season. As a result, fish recruitment decreases and fish diversity gradually decreases as breeding success drops.

The biological integrity of Assam's freshwater ecosystems has been severely compromised by the combined effects of habitat degradation, pollution, wetland conversion, exotic aquatic vegetation, overexploitation, hydrological shifts and climate-induced changes. These interrelated pressures impact the livelihoods and food security of populations that rely on fisheries, in addition to endangering the existence of native fish species. Integrated conservation strategies that put an emphasis on pollution prevention, sustainable fisheries management, habitat restoration and the preservation of rivers and wetlands as interdependent natural systems are necessary to address these issues.

3. Conservation Strategies for Indigenous Fish Species in Assam's Rivers and Wetlands

An integrated strategy that incorporates habitat restoration, sustainable fisheries management, legal protection, scientific interventions and active community involvement is necessary for the conservation of native fish species. Conservation efforts must concentrate on preserving the ecological integrity of rivers and wetlands while guaranteeing the sustainable use of fishing resources, given the mounting challenges posed by pollution, overexploitation, habitat degradation, and hydrological changes. The state's unique freshwater fish species may be greatly preserved by a combination of government programs, scientific advancements, and local community involvement.

The creation of Pocket Habitat Areas (PHAs) is one of the new conservation strategies. These are tiny, carefully planned, undisturbed areas that serve as microhabitats for native fish species in the curved portions of river systems. Throughout the many phases of the fish life cycle, PHAs offer appropriate environmental conditions for eating, breeding, shelter, and growth. This novel approach has the potential to improve native fish population conservation in both rivers and wetlands by preserving ecological connection and shielding vital habitats from human interference.

Conserving biomass is another crucial tactic for protecting habitats. Stretches of rivers and wetlands that are ecologically

vulnerable should be designated as protected areas, where fishing and other damaging activities are either forbidden or subject to stringent regulations. Fish populations can naturally reproduce and rejuvenate in these protected areas, which helps replenish depleted fish stocks and improve aquatic biodiversity.

Also, equally crucial is the efficient application of current legal rules. By outlawing damaging fishing methods like the use of explosives and toxic materials in water bodies, the Indian Fisheries Act, 1897 has significant measures for fish conservation (Biradar & Ayyappan, 2021). The illicit fishing methods that endanger native fish populations can be considerably reduced with strict enforcement of these rules, frequent monitoring, and suitable sanctions for infractions.

A unique cultural practice in many regions of Northeast India, traditional community and festival fishing also needs to be carefully regulated. Fish populations can be significantly reduced by indiscriminate harvesting involving large groups of people, especially during breeding seasons, even though these events have significant social and cultural value. Cultural customs and biodiversity protection can be balanced by establishing community rules, seasonal limits and awareness among local people.

In order to promote conservation, public awareness and capacity-building initiatives are essential. Awareness campaigns should promote environmentally sustainable agricultural practices, such as switching from chemical fertilizers and pesticides to organic ones, and inform farmers, fishermen, and local communities about the ecological and economic significance of native fish species. In a similar vein, training courses, seminars, and workshops on sustainable aquaculture and indigenous fish conservation can boost local expertise and promote broader involvement in conservation initiatives.

Through technical support, financial incentives, and extension services, government agencies, research institutions, and non-governmental organizations (NGOs) should aggressively promote the culture and conservation of native fish species. In addition to helping to conserve biodiversity, supporting indigenous fish farming gives rural populations alternate sources of income, which lessens the strain on natural fish stocks. Community involvement is a crucial part of conservation. Local

communities must actively participate in the design, monitoring and implementation of conservation measures because they are the main users and stewards of rivers and wetlands. Initiatives for community-based conservation can increase adherence to conservation laws, promote local stewardship, and combine scientific management techniques with traditional ecological knowledge.

Through the Wetland Rejuvenation Project, the Assam Government has also started ecological restoration initiatives in recent years. The government announced plans in 2024 to revitalize 129 wetlands (beels) totaling around 3,800 hectares throughout the state in cooperation with the Asian Development Bank (ADB). The project intends to boost the biological functioning of these significant freshwater habitats while improving water storage capacity, restoring damaged wetland ecosystems, and protecting native fish species (Baruah, 2024).

In general, a comprehensive and ecosystem-based strategy that incorporates habitat restoration, law enforcement, scientific management, sustainable harvesting methods, public awareness, and community involvement is needed to conserve native fish species of Assam. In order to protect the state's rich freshwater biodiversity and guarantee the long-term viability of fisheries and the livelihoods that depend on them, such coordinated measures are crucial.

4. Conclusion

Assam's rich freshwater biodiversity, ecological sustainability, food security, and rural livelihoods all depend on the preservation of native fish species in the state's rivers and wetlands. In addition to offering high-quality protein, vitamins, minerals, and other vital nutrients, indigenous fish also make a substantial contribution to the socioeconomic well-being of communities who rely on inland fisheries. However, these important fish resources are under a lot of stress due to growing habitat degradation, pollution, wetland conversion, overexploitation, invasive aquatic vegetation, and hydrological changes. A thorough and integrated conservation strategy that incorporates habitat preservation, sustainable fisheries management, scientific interventions, and efficient enforcement of current legal requirements is needed to address these issues. Pocket

Habitat Areas, fish ranching programs, wetland rejuvenation, and protected aquatic habitats are examples of innovative approaches that have promising prospects for replenishing diminishing fish populations. The active involvement of local communities in awareness campaigns, sustainable fishing methods, and community-based conservation projects is equally crucial. Maintaining healthy aquatic ecosystems requires strict monitoring of damaging fishing practices, such as poisoning, careless harvesting during breeding seasons, and overuse of pesticides in nearby agricultural fields. Assam can preserve its native fish diversity while maintaining the long-term ecological integrity of its rivers and wetlands and promoting sustainable livelihoods for future generations through concerted efforts involving government agencies, academic institutions, non-governmental organizations and local communities.

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8

Sustainable Livelihoods and Wetland Conservation: Assessing the Socio-Economic Impact of Environmental Degradation in Deepor Beel on Indigenous Fishing Community

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ABSTRACT

At the periphery of Guwahati metropolitan city, the scenic wetlands of Deepor Beel have long supported the livelihood of native fishing communities, giving them not only a livelihood but also a strong cultural attachment to the land. But the sudden deterioration of this critical ecosystem, under threat from pollution, encroachment, and environmental mismanagement, has left these communities at the mercy of forces beyond their control. What was once an endless supply of livelihood has now become the face of hardship. This research aims to bring to light the deep, but not-so-often-discussed, effect of ecological degradation on the socio-economic lives of these fishing communities.

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With week-long field research comprising interviews, field visits and rich community dialogue in nine villages, the study brings out the intricate array of problems faced by these households. Through a concentration on the lived realities of the people whose livelihoods are deeply embedded in the lake, the research examines how livelihoods that have been centuries old are being lost, as well as highlighting the adaptability and resilience of this group. The results seek to inform the urgent necessity for context-sensitive, balanced, sustainable policies that can conserve both the environment and the livelihood of the community. This research aims to ignite a conversation on the interconnectedness of environmental sustainability and human well-being, advocating for solutions that honor both ecological health and social justice by mitigating challenges of climate change and environmental degradation.

Keywords: *Climate Change, Wetland Conservation, Sustainable Development, Livelihood, Fishing Community, Deepor Beel.*

1. Introduction

It was a humid afternoon in the midst of the spring season, and the skies above Deepor Beel were thick with the anticipation of rain. Situated around 10 kilometers southwest of Guwahati, this expansive freshwater wetland sat in peaceful stillness, a distant boat in view adding to the scenic beauty of the site. Inside the boat, a 50-year-old fisherman rowed with practiced ease, his movements reflecting a lifetime of knowledge passed down through generations. For him and the over 800 families who depend on the *Beel*, the lake is more than just water; it is their source of sustenance, their cultural heritage, and a way of life that has endured for centuries. For these communities, Deepor Beel is not just geography; it is heritage, sustenance and identity.

Deepor Beel, covering over 40.14 sq. km, is the largest wetland in the Brahmaputra Valley and the only Ramsar site in Assam, designated for its ecological significance and biodiversity richness (Ramsar Secretariat, 2002). In 2001, it was also notified as a wildlife sanctuary under the Wildlife Protection Act, 1972, due to its critical role in supporting over 200 avian species, including 70 migratory birds (Das & Ahmed, 2021). Beyond being an avian refuge, the wetland provides flood control and

groundwater recharge and sustains local livelihoods, especially of the marginalized communities whose survival is woven into its ecology. However, Deepor Beel today stands as a site of ecological fragility and administrative neglect. The Pollution Control Board, Assam (2023), reported dangerously high Biochemical Oxygen Demand (BOD) levels and fluctuating pH values in the Beel's waters, threatening aquatic biodiversity. The nearby municipal dumping ground at Boragaon, located barely 500 meters from the wetland, continues to leach hazardous waste into the ecosystem (The Times of India, 2024). Illegal encroachments, railway expansion, and unregulated urban runoff have furthered degradation, despite legal protections. Judicial interventions have attempted to safeguard the wetland. The Gauhati High Court, in PIL Nos. 3/2017 and 40/2021, ordered the relocation of the dumping ground and mandated the implementation of the Wetlands (Conservation and Management) Rules, 2017 (The Sentinel Assam, 2022). In a more recent 2025 ruling, the Court directed the cessation of unauthorized earth-filling and called for restoration of the Beel's ecological integrity (The Legal Affair, 2025). Yet, these court-mandated actions have only partially stemmed the tide of deterioration. To understand the implications of this crisis, this study adopts the Sustainable Livelihoods Framework (SLF), developed by the Department for International Development (DFID, 1999). Sustainable livelihood, unlike conventional livelihood approaches that focus primarily on meeting immediate economic needs, takes a long-term, inclusive view. It integrates economic, social, and environmental dimensions, ensuring that current and future generations can meet their needs without compromising ecological health. It emphasizes resilience through diversification of skills and income, promotes equity and inclusion, and encourages participatory governance for empowerment and justice. At its core lies the responsible use of natural resources and the conservation of biodiversity, a principle acutely relevant in the context of Deepor Beel's fragile ecosystem. This study thus seeks to critically examine how the environmental decline of Deepor Beel impacts the livelihood strategies of its indigenous fishing communities, not merely in terms of income, but also dignity, agency, and survival.

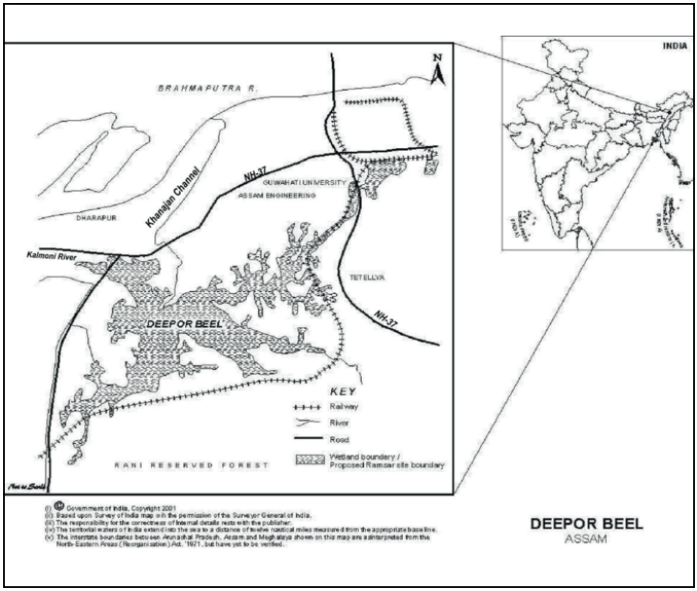


Figure 1: Map of Deepor Beel

Source: Ramsar website. Retrieved on 31 December 2019 from, https://rsis.ramsar.org/RISapp/files/41543220/pictures/IN1207map.pdf

1. Methodology Of The Study

This study adopts a qualitative and exploratory design to examine the socio-economic impacts of environmental degradation on indigenous fishing communities dependent on Deepor Beel, Assam. Fieldwork was conducted over one week in April 2025 across nine villages in the Deepor Beel area of Kamrup Metropolitan district, Noapara, Hirapara, Keotpara, Hatowapara, Notun-Bosti, Chorapara, Borbori, Matia-Pahar, and Namdhorabori, predominantly inhabited by Hira, Kaibartta, and Jaliya fishing communities recognized as Scheduled Castes under the Constitution (Scheduled Castes) Order, 1950 (Ministry of Law and Justice, 1950). Purposive sampling was used to select participants with long-term dependence on fishing-based livelihoods. Semi-structured interviews were conducted with 25 households, supplemented by key informant interviews with community elders, local leaders, NGO representatives, and nearby forest department officials. Field observations documented fishing practices, ecological degradation, waste

disposal, and everyday interactions between the community and the wetland. Secondary data from government reports, court orders, environmental assessments, academic literature, and publications by conservation organizations, including the Ramsar Convention, Wetlands International, and the International Union for Conservation of Nature, were used to contextualize the findings. Qualitative data were analyzed using thematic analysis, with interview transcripts and field notes manually coded to identify recurring patterns related to livelihood insecurity, occupational transition, migration, gendered impacts, and cultural alienation. Ethical protocols were followed throughout the study; informed consent was obtained, confidentiality was maintained, and sensitive issues were discussed only when voluntarily raised. Given the limited sample size and short fieldwork duration, the findings are exploratory and context-specific. The study covered 25 households across the nine villages, with a mean respondent age of 45 years. Fishing constituted the primary occupation for all households, contributing over 75 percent of household income and representing a generational livelihood. Respondents reported significant income loss and a gradual shift away from traditional fishing, with female respondents highlighting pronounced familial and gendered consequences, discussed in subsequent sections.

2. Environmental Degradation of Deepor Beel

Over the past few decades, Deepor Beel has faced severe environmental degradation due to multiple anthropogenic and anti-ecological practices.

3.1. Waste Dumping

According to the Pollution Control Board, Assam, the total area of the polluted stretch of Deepor Beel is 40.14 sq km. The area has been suffering from environmental degradation due to continuous encroachment and waste dumping, as the Guwahati Municipality dumpyard (24 Ha) located in Boragaon lies in the eastern corner of the Deepor Beel. The dumping of municipal solid wastes in its close proximity at Boragaon by the Guwahati Municipal Corporation (GMC) has pushed the wetland's pollution to alarming levels. The problem gets aggravated during the monsoons, with rainwater sweeping large amounts

of garbage from the dumping site to the Beel. This dumping practice has over the years, as many local fishermen emphasised , has led to the growing density and coverage of the Beel's water by water hyacinth, making the BOD of the wetland rise to an alarming rate where local fish species have declined due to the shortage of dissolved oxygen in the waters of the Beel.

3.2. Invasive Species

The spread of invasive aquatic species is another factor accelerating the ecological imbalance in Deepor Beel. In the field study, there were two invasive species emphasised by the local fishermen:

Water Hyacinth (*Eichhornia crassipes*): Known as the terror of Bengal, this non-native, fast-growing plant has proliferated across the wetland, choking water channels, blocking sunlight, and reducing oxygen levels in the water. These species alter the native aquatic plant community structure, hinder water transport, and impact fish populations by disrupting breeding habitats. It has also been detrimental to the growth of Prickly Water Lily (*Euryale ferox)* in the Beel waters, the plant from which '*Makhana'*(fox nut) is extracted which could have significant economic benefits.



Figure 2: Water Hyacinth (Eichhornia crassipes)

Source: Center for Aquatic and Invasive Plants, University of Florida, IFAS.

Suckermouth Catfish (*Hypostomus plecostomus)* : As reported by the local fishermen, this variety of fish is known for its high adaptive capabilities under extreme circumstances. Moreover, the eggs of other smaller fishes constitute a part of its food. The fish also lacks economic value in the local fish markets. So, the fishermen cannot sell them either. Under these grounds, this fish species not only reduces the native, economically viable fish varieties but also provides no economic output in itself to the fishermen.



Figure 3: Suckermouth Catfish (Hypostomus plecostomus)

Source: Author's own. Captured during the fieldwork.

3.3. Illegal Construction

The third factor that has been affecting the Beel and eventually the fishermen is the illegal construction activities. Encroachment and illegal construction activities pose a direct threat to the wetland's physical boundaries and ecological character. Infrastructure projects, including a railway line cutting through the beel, have fragmented the wetland and disrupted hydrological connectivity. Adding to that, the rapid urbanization of Guwahati has led to unauthorized residential and commercial construction in and around the wetland, reducing its area. Moreover, satellite imagery and field reports indicate continued land grabbing and illegal settlements within the wetland boundary, in violation of the Wetlands (Conservation and Management) Rules, 2017. Such development undermines conservation efforts, reduces flood buffering capacity, and increases human-wildlife conflicts.

3.4. Overfishing

Overexploitation of aquatic resources, especially unsustainable fishing practices, has had a cascading effect on the wetland ecosystem. The continued fishing activities during the breeding season of the fishes have also reduced the fish population. Traditional fishing communities, who rely on the beel for subsistence, face economic instability due to this dwindling fish population.

3.5. The environmental impact of the Kamakhya-Jogighopa railway line

The Kamakhya-Jogighopa railway line traverses Deepor Beel, a habitat for diverse wildlife, including the endangered Asiatic elephant. The railway line, constructed in 2001, has fragmented the wetland, disrupting hydrological regimes and leading to habitat degradation. Notably, several elephants have died due to collisions with trains along this route (Sharma et al., 2015). In response to environmental concerns, the National Board for Wildlife approved the construction of elevated corridors in 2024 to mitigate wildlife fatalities and restore ecological connectivity (The Sentinel Assam, 2024). However, challenges persist, including pollution from urban runoff and encroachment, which threaten the wetland's integrity (Down To Earth, 2021).

4. The Socio-economic Impact of the Ecological Degradation of Deepor Beel on the Livelihoods of Indigenous Fishing Communities

The analysis of the findings and conclusions from the field visit, interviews, and the analysis of both the primary and the secondary data reveals the following socio-economic impact of the ecological degradation of Deepor Beel on the indigenous fishing community:

4.1 Financial Burden

The ecological decline of Deepor Beel has also placed an increasing financial burden on local fisherfolk, where many families are struggling to meet daily expenses. As income from fishing continues to shrink, community members are increasingly turning to local moneylenders to bridge the financial gap, often at exorbitant interest rates. "We had no choice but to borrow money when our catch was reduced. The bank needs

paperwork we don't have, but the moneylender is more feasible for us. Now, we pay more in interest than we earn," explained by a female respondent (personal interview, April 2025). These informal credit arrangements, while offering immediate relief, have led to cycles of debt and dependency, further deepening poverty and vulnerability within the community. The lack of institutional financial support or targeted government intervention compounds the issue, leaving families trapped between environmental degradation and financial exploitation.

4.2 Migration

The ecological degradation has led to a marked shift in the socio-economic fabric of the local fishing population, with many families being forced to migrate in search of alternative livelihoods. "We can no longer depend on the lake for fishing like before. The water smells bad, and the fish have either disappeared or are diseased. My brother has moved to Guwahati to work as a daily wage laborer," said Rupam Kaivratta (personal interview, April, 2025), a traditional fisherman narrating in the evening fish market. Such testimonials highlight a growing trend of displacement and occupational shift, threatening the cultural identity and traditional knowledge systems of the fishing community in Deepor Beel. The government has prohibited fishing in the core zone of the lake. Additionally, authorities frequently impose restrictions on community fishing, particularly in January during the celebration of Magh Bihu, Assam's most significant traditional festival. This January, the official order declared community fishing to be illegal under the Wildlife (Protection) Act, 1972, citing its severe and lasting harm to the ecosystem of Deepor Beel, a designated wildlife sanctuary. Over time, many individuals from Assam's indigenous *Keot* community, who traditionally relied on fishing, have been compelled to leave Deepor Beel in search of alternative livelihoods. The local population has strongly resisted these restrictions, emphasizing that fishing has been deeply woven into their social, economic, and cultural lives for generations (ICSF, n.d.). In addition to fishing, local residents heavily rely on the beel for edible plants, herbal medicines, animal fodder, grazing land, and firewood. Many locals believe that fishermen are among the few remaining individuals actively defending and preserving Deepor Beel from complete ecological collapse.

4.3 Impact on the Familial Life

The ecological degradation and its impact on fishing have intensified economic insecurity among fishermen. This financial stress is manifesting in rising cases of domestic violence. As observed during fieldwork, a disturbing trend of increased alcohol abuse and physical assault within households. A female respondent, whose identity is withheld for ethical reasons, recounted: "When there is no fish, there is no money. My husband returns drunk and angry. He takes it out on me and our children" (Field interview, 2025). Such testimonies underline the gendered and familial consequences of environmental collapse, where women and children bear the brunt of ecological and economic vulnerability. The degradation of Deepor Beel thus not only threatens biodiversity but also destabilizes human relationships, exposing the intricate link between environmental sustainability and social well-being.

4.4 Alienation from the Traditional Occupation

The ecological degradation of Deepor Beel has also led to a gradual alienation of the local fishing community from their traditional occupation, once the cornerstone of their identity and economy. With the declining profitability of fishing and increasing environmental challenges, many community members, especially the younger generation, are distancing themselves from this ancestral livelihood. Fishing, which once held cultural significance, is now perceived as a symbol of economic struggle and low social status. "My son doesn't want to do what I do. He says there's no respect or future in fishing anymore. He's trying for a job in a private company in the city," shared Damodor Hira (personal interview, April 2025). The search for dignity, financial stability, and upward mobility has prompted youth to explore opportunities in urban employment, small businesses, and vocational training programs. This shift reflects a broader trend of occupational transition driven by environmental stress and the perceived erosion of traditional livelihoods, marking a significant cultural and economic transformation within the community.

5. Analysis and Discussion

The findings from the field study in Deepor Beel reveal a deeply interwoven relationship between ecological degradation and

the socio-economic vulnerabilities of the indigenous fishing communities. The responses collected through interviews and informal conversations underscore a shift not only in occupational trends but also in the social, familial, and cultural dynamics of these communities. The data clearly illustrates a transition away from generational fishing as a sustainable livelihood. With 100% of households previously dependent on fishing, the recent shift towards alternative livelihoods, largely unskilled and informal urban employment, signals a collapse in the occupational backbone of the community. The migration trend among the youth and male members in Deepor Beel indicates a broader occupational dislocation and loss of cultural identity. Respondents spoke of seeking dignity and better prospects outside of fishing, viewing it now as a symbol of economic desperation rather than tradition. Furthermore, the legal restrictions during cultural festivals like Magh Bihu not only add to the economic strain but are perceived by locals as an attack on their cultural rights. The socio-economic strain caused by environmental degradation has tangible domestic consequences, especially on women and children. Testimonies during the fieldwork revealed a rise in alcohol abuse and domestic violence. These accounts challenge the traditionally narrow view of ecological degradation as a purely biological or environmental issue, instead asserting it as a deeply social and gendered crisis. The younger generation's distancing from fishing also reflects a breakdown in the intergenerational transfer of ecological knowledge that has been central to the sustainable management of the Beel. Local voices argue that fishermen are the true stewards of the wetland. The study also brings into sharp focus how anthropogenic pressures, waste dumping, invasive species, illegal construction, and overfishing, interact to produce a compounded ecological crisis. The analysis reveals that the socio-economic impacts observed in Deepor Beel are both a cause and a consequence of ecological degradation, embedded within a larger framework of environmental injustice and policy neglect. While the problems resonate with global patterns seen in similar wetland ecosystems, the Deepor Beel case highlights the urgent need for: Context-sensitive conservation models; Empowerment of local communities, especially women; Recognition of traditional ecological knowledge; And policies that balance ecological protection with socio-economic rights.

In short, the Deepor Beel crisis exemplifies a collapse not only of ecosystem services but of a centuries-old socio-cultural ecosystem rooted in the indigenous fishing traditions of Assam.

Conclusion

Deepor Beel, the only Ramsar site in Assam, continues to be suffering from environmental degradation due to encroachment and other major issues. The study reflects the close association of various social, economic, political, ecological, and cultural factors contributing to its deterioration. It generates the need to take strict control of the industrial pollution and the effective implementation of the Action Plan for rejuvenation, protection, and management of the Beel. Strong locally organized drives to address both environmental and community needs are of urgent requirement. A stronger voice at the community level would contribute towards generating awareness. As the study reflects, the majority of the fishing community is primarily dependent on it, and there are no other employment avenues for them. So, providing them with alternative livelihood opportunities and effective beneficiary programs to uplift them would be helpful in improving their condition. A well-thought-out environmental policy taking into consideration both the sustainable environment and community needs is required. In assisting this, further research by individuals, civil society, and the state would be helpful factors.

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9

Governance, Policy Frameworks, and Regional Collaboration for Climate Resilience in the Eastern Himalayas: Insights from Northeast India

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ABSTRACT

The Eastern Himalayan region, which includes Northeast India, stands as both an ecologically sensitive and culturally heterogeneous landscape. Acceleration of climate change has intensified existing vulnerabilities, manifesting through irregular rainfall patterns, glacial melting and decline of biodiversity, thereby complicating policy and governance responses. This chapter critically explores how governance mechanisms, policy designs, and regional cooperation interact to enhance climate resilience within the Eastern Himalayas, with particular attention to Northeast India. It traces the trajectory of climate policy development at national and state levels, focusing on instruments such as the State Action Plans on Climate Change (SAPCCs), and evaluates their alignment with regional frameworks like ICIMOD, SAARC, and the Brahmaputra Dialogue.

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Using an interdisciplinary lens that merges political ecology, institutional analysis, and environmental policy studies, the chapter highlights governance deficiencies, coordination barriers, and successful practices of collaborative engagement. Empirical cases from Assam, Arunachal Pradesh, and Sikkim demonstrate that adaptive governance, participatory approaches, and transboundary cooperation form the foundation of resilient mountain ecosystems. The chapter ultimately advocates for a model of polycentric and multi-level climate governance that integrates local innovations with regional and diplomatic initiatives crucial for advancing sustainable climate resilience in the Eastern Himalayas.

Keywords: *Climate Governance, Regional Cooperation, Climate Resilience, Transboundary Cooperation, Environmental Policy*

1. Introduction: Climate Change and Governance in the Eastern Himalayas

The Eastern Himalayas, which include much of Northeast India, form one of the planet's most ecologically delicate and culturally diverse mountain regions. Designated as part of the Himalayan biodiversity hotspot, this area features elevated endemism, intricate altitudinal ecosystems, and glacier-sourced river systems that support populations downstream (Myers et al., 2000; Xu et al., 2009). At the same time, Northeast India shelters varied indigenous and tribal groups whose livelihoods, traditional institutions, and worldviews are profoundly intertwined with forested and riverine environments (Karlsson, 2011). This fusion of ecological fragility and socio-cultural variety makes the region highly susceptible to climate disruptions.

Current climate patterns reveal growing fluctuations in monsoon rains, heightened flooding in the Brahmaputra basin, and rapid glacial melting in the Eastern Himalayan cryosphere (Singh et al., 2011; Bolch et al., 2012). Unpredictable precipitation and severe weather incidents have disturbed agricultural practices and amplified risks of landslides and soil erosion in hill areas (Dash et al., 2007). Losses in biodiversity and forest cover additionally endanger ecosystem services vital for food security, water management, and regional economies (Tiwari et al., 2010). These linked threats highlight the shortcomings of traditional

sectoral development strategies in tackling multifaceted climate risks.

In mountainous settings, resilience hinges on governance structures. Adaptive potential relies not just on physical infrastructure but on effective institutional collaboration, inclusive decision processes, and the blending of scientific insights with indigenous ecological knowledge (Adger et al., 2005; Ostrom, 2010). India's climate governance framework-rooted in the National Action Plan on Climate Change and executed via State Action Plans on Climate Change (SAPCCs) aims to embed adaptation across sectors (Dubash et al., 2018). Yet, execution in Northeast India occurs amid a complex governance terrain characterized by constitutional disparities, Autonomous District Councils, and traditional bodies, frequently leading to coordination shortfalls and policy silos (Ghosh & Schmidt, 2011).

This chapter analytically investigates how governance systems, policy structures, and regional partnerships work together to bolster climate resilience in the Eastern Himalayas. Employing political ecology, institutional analysis, and environmental policy scholarship, it probes how power dynamics, institutional configurations, and cross-border factors influence adaptation results. By placing Northeast India in wider Himalayan contexts like ICIMOD and transboundary river discussions, the chapter promotes a polycentric, multi-level approach to climate governance tailored to mountain environments.

2. Theoretical and Analytical Framework

Understanding climate resilience in the Eastern Himalayas requires an interdisciplinary approach placing environmental changes within political, institutional, and socio-ecological contexts. This chapter merges political ecology, multi-level governance, and resilience theory to analyse how power, institutions, and ecology shape adaptation in Northeast India.

2.1 Political Ecology and Mountain Vulnerability

Political ecology critically examines socially differentiated, politically mediated environmental risks. It views climate change not as isolated biophysical force but embedded in power, resource control, and historical inequities (Blaikie & Brookfield, 1987; Robbins, 2012). In Eastern Himalayas, forest/water/

land access reflects colonial legacies, state policies, traditional systems determining exposure and adaptation benefits.

Justice concerns loom large in Northeast India: tribes depend on ecosystems yet hold weak national policy sway (Karlsson, 2011). Climate shifts (erratic rains, biodiversity decline) compound inequalities, redistributing risks unevenly (Adger et al., 2006). This lens scrutinizes valued knowledge in planning and development's ecological toll.

2.2 Institutional and Multi-Level Governance Theory

Institutional theory shows how formal/informal rules enable shared resource management. Ostrom's (2010) polycentric model boosts resilience via autonomous, cooperating centres across scales in Himalayas: national/state/Autonomous District Councils/village institutions.

Adaptation succeeds through vertical (local-state-national) and horizontal (forestry-water-disaster) coordination (Cash et al., 2006). Fragmentation breeds policy gaps; multi-level views urge alignment for transboundary challenges.

2.3 Climate Resilience in Mountain Ecosystems

Resilience theory depicts mountains as complex social-ecological systems with feedbacks/thresholds (Folke, 2006). Adaptive capacity means anticipating/responding/learning from shocks. Himalayan resilience depends on biodiversity protection, ecosystem services, and inclusive governance fostering collective flexibility.

3. Climate Risk and Vulnerability in Northeast India

Northeast India, in the Eastern Himalayan arc, confronts rising, linked climate risks. Its diverse topography, fragile slopes, vast rivers, and resource dependence amplify hydro-climatic sensitivity. Change manifests as variability, extremes, and disruption beyond mere warming (Singh et al., 2011). Key focuses: hydrology, ecology, socio-economics.

3.1 Hydro-climatic Changes

Monsoon irregularity signals change: variable rains with delayed onset, shorter spells, intense bursts cause floods/droughts, disrupting agriculture and rural stability (Dash et al., 2007).

The Brahmaputra, Asia's major transboundary basin, reflects instability—glacial melt plus heavy rains worsen Assam floods/erosion (Shrestha et al., 2012). Sedimentation, shifting channels, embankment failures complicate control; shared by China/India/Bhutan/Bangladesh, geopolitics looms.

Eastern Himalayan Glacier Rivers retreat/thin, threatening water security despite fewer large glaciers vs. west (Xu et al., 2009). Altered snowmelt affects dry-season flows for irrigation, power, and ecosystems.

3.2 Ecological Impacts

Fluctuations heighten stress. Renowned for biodiversity, the Himalayas see species shifts/habitat loss from temperature/precipitation changes (Myers et al., 2000). Human/climate-driven deforestation cuts carbon sinks, slope stability.

Intense rains spur landslides/erosion in Arunachal/Meghalaya; logging/roads exacerbate, eroding farmland/infrastructure and resilience services.

3.3 Socio-economic Sensitivities

Socio-economics deepen vulnerability. Tribes rely on forests, jhum cultivation, rivers (Karlsson, 2011). Rain-fed farming reacts sharply to variability/floods.

Women face heightened burdens in water/firewood/food tasks, amplifying exposure (Adger et al., 2006). These layers show climate risks as ecological/socio-political, needing integrated governance.

4. Evolution of Climate Governance in India and Northeast India

India's climate governance has evolved through embedding policies that integrate mitigation and adaptation into development. While global positions emphasize equity and differentiated duties, domestic efforts focus on sector-wide climate mainstreaming (Dubash et al., 2018). This matters greatly for Northeast India and the Eastern Himalayas, with their ecological fragility, disaster exposure, and constitutional governance gaps.

4.1 National Climate Policy Trajectory

Launched in 2008, the National Action Plan on Climate Change (NAPCC) marked a milestone, detailing eight National Missions

on sustainable agriculture, water, Himalayan ecosystems, and climate knowledge. The Himalayan Ecosystem Mission is key for Northeast India, addressing glacier melt, biodiversity loss, and hydrological shifts (Jörgensen et al., 2015). Critics note its mission structure lacks strong accountability and adaptation metrics (Dubash et al., 2018).

Paris Agreement NDCs, updated later, tie climate targets to sustainable goals, prioritizing renewables, forests, and resilient infrastructure. Adaptation lags behind mitigation, particularly in mountains needing localized responses (Immerszeel et al., 2010).

The 2005 Disaster Management Act bridges climate and risk reduction by forming the NDMA and state bodies for preparedness. Adaptation aligns with disaster strategies in flood-hit Assam, but climate-disaster coordination remains patchy, leading to solied planning.

4.2 State Action Plans on Climate Change (SAPCCs)

States developed SAPCCs to localize NAPCC, tailoring missions to vulnerabilities, sectors, and strategies. Northeast SAPCCs target agriculture, forestry, water, and disasters, matching regional risks.

Implementation falters: many rely on secondary data without district-level assessments (Panda, 2013). Funding ties to central schemes limit flexibility; monitoring is weak, stalling progress tracking.

State climate cells lack staff and expertise in modelling; departmental silos hinder integrated adaptation.

4.3 Governance Deficiencies

Fragmentation breeds overlaps and inconsistencies (Ghosh & Schmidt, 2011). Budget constraints in hill states curb investments; transparency gaps erode accountability.

These demand multi-level coordination, fiscal decentralization, and participatory reforms for effective Himalayan vulnerability responses.

5. Regional Cooperation and Transboundary Governance

Climate resilience in the Eastern Himalayas requires actions transcending national borders. Its ecosystems river basins,

glaciers, forests, and biodiversity corridors link India with Bhutan, Nepal, China, and Bangladesh. Regional partnerships and transboundary governance thus are vital for adaptive capacity, though existing platforms face geopolitical, institutional, and capacity hurdles.

5.1 ICIMOD and Himalayan Regionalism

The International Centre for Integrated Mountain Development (ICIMOD) acts as a key knowledge platform for Himalayan cooperation. Aimed at sustainable development in the Hindu Kush Himalaya, it enables data sharing, research, and policy talks among members. Programs like the Hindu Kush Himalayan Monitoring and Assessment Programme (HIMAP) provide in-depth analyses of climate impacts, glacier retreat, and ecosystem threats (Wester et al., 2019), fostering shared awareness and evidence-based adaptation.

ICIMOD pushes ecosystem-focused strategies, cryosphere monitoring, and community resilience by blending science with local knowledge for cross-border learning. Yet, its advisory nature limits influence on disputes like water sharing and hydropower without binding authority.

5.2 SAARC and Climate Diplomacy

The South Asian Association for Regional Cooperation (SAARC) offers another channel via the SAARC Action Plan on Climate Change and Disaster Management Centre, seeking unified responses to hazards through adaptation, risk reduction, and capacity building.

However, geopolitical tensions and weak cohesion undermine SAARC. Rivalries sideline environmental goals, leading to poor pledge fulfilment. Diverse capacities, economies, and vulnerabilities hinder policy harmony, stalling diplomacy into action.

5.3 Brahmaputra Dialogue and River Basin Governance

The Brahmaputra basin highlights transboundary water challenges, flowing from Tibet through India and Bangladesh to sustain millions. Limited sharing persists, mostly seasonal flood data, amid concerns over upstream dams (Rahaman, 2012). Data opacity impedes forecasting and trust. The Brahmaputra Dialogue promotes informal stakeholder engagement for resilient governance, but lacks a basin treaty for stability.

5.4 Limits of Regional Cooperation

Shared ecology notwithstanding, cooperation is constrained by geopolitics, sovereignty, and capacity gaps. Larger states dominate with resources, marginalizing smaller ones. Fostering trust, transparency, and equity is key to robust transboundary frameworks.

6. Empirical Case Studies from Northeast India

Real-world examples from Northeast India reveal how governance creativity, community involvement, and policy trials influence climate resilience on the ground. The experiences of Assam, Arunachal Pradesh, and Sikkim showcase varied strategies for flood control, forest management, and sustainable farming amid the Eastern Himalayan socio-ecological context.

6.1 Assam: Flood Governance and River Management

Assam stands as one of India's most flood-vulnerable states, owing to its position in the volatile Brahmaputra basin. Yearly floods, worsened by sediment build up, bank erosion, and intense rains, have grown more severe amid climate shifts (IPCC, 2022; Rahman & Gain, 2020). Traditionally, Assam's flood tactics centered on engineered solutions, mainly embankments built since the 1950s. Yet, frequent breaches and rising upkeep expenses have highlighted the drawbacks of engineering-only flood mitigation (Baruah, 2007).

Lately, governance shifts prioritize holistic river basin oversight and nature-friendly methods. Discussions now stress blending hard defences with watershed restoration, wetland protection, and zoning of floodplains. Moreover, better synchronization between the Assam State Disaster Management Authority and water agencies has bolstered proactive strategies under the Disaster Management Act (Shaw et al., 2013).

Local early warning networks have become vital adaptation instruments. Backed by government and civil society, they merge hydrological info with community channels for swift flood notifications. Inclusive methods build confidence and ensure outreach, cutting deaths and economic harm from disasters (Adger et al., 2005). Still, ongoing transboundary data gaps in the Brahmaputra hinder enduring resilience (Rahaman, 2012).

6.2 Arunachal Pradesh: Forest Governance and Biodiversity

With more than 75 percent forest coverage, Arunachal Pradesh is essential for upholding Eastern Himalayan biodiversity and moderating local climate patterns (Ravindranath et al., 2006). Yet, road growth, hydropower schemes, and rotational farming combine with climate changes to heighten environmental strain.

Community-led forest oversight, grounded in traditional bodies, serves as a key resilience strength. Local councils oversee forest use, safeguard sacred areas, and control harvesting via cultural rules. These localized systems align with Ostrom's (2010) ideas on managing shared resources, stressing community rules and oversight.

Native ecological wisdom bolsters adaptability by guiding crop choices, forest care, and species protection (Karlsson, 2011). Knowledge of seasonal cues, biodiversity, and customary land practices aids flexibility against climate unpredictability. Although official policies now value community roles, blending legal systems with traditions stays patchy, curbing polycentric adaptation's reach.

6.3 Sikkim: Organic Policy and Climate Adaptation

Sikkim offers a unique model of tying environmental health to climate strength. Its full shift to organic farming, driven by policy changes and farmer education, aimed to improve soil quality, biodiversity, and lasting sustainability (Panneerselvam et al., 2012). Banning chemical inputs cuts degradation and boosts soil water-holding, aiding resilience to rain shifts (Lal, 2013).

Governance advances drove Sikkim's change. Unified efforts by agriculture offices, certifiers, and cooperatives ensured policy unity and execution. Linking watershed care, eco-tourism, and green farming shows how to embed climate adaptation in wider development (Wester et al., 2019).

Collectively, these cases show that Northeast India's climate resilience relies on flexible governance, inclusive bodies, and tailored policy approaches.

7. Towards Polycentric and Multi-Level Climate Governance

Boosting climate resilience in the Eastern Himalayas calls for moving beyond disjointed, sector-focused actions to a polycentric, multi-level governance system equipped to handle intricate

socio-ecological issues. Considering the area's constitutional differences and robust traditional practices, linking local bodies with official state structures is vital. Traditional village councils, Autonomous District Councils, and native systems already oversee forests, water, and land in much of Northeast India (Karlsson, 2011). Incorporating them into State Action Plans on Climate Change (SAPCCs) boosts credibility, local fit, and community buy-in. This approach mirrors Ostrom's (2010) polycentric model, featuring independent authority centres that align via common rules and data flows.

Financial devolution forms a key foundation. Successful adaptation needs reliable, adaptable funds for local trials and creativity. Yet, northeastern states often lean on central programs, restricting flexible adaptation outlays (Dubash et al., 2018). Bolstering state climate funding, improving national fund access, and advancing climate-aware local plans can heighten vertical unity and responsibility.

Regional partnerships also require reinforcement to oversee joint ecosystems, especially rivers like the Brahmaputra. Trust measures, data pacts, and shared research can ease water politics and fortify basin resilience (Rahaman, 2012). Venues like ICIMOD highlight knowledge-sharing benefits, but shifting talks to enforceable deals stays urgent.

Digital tools for climate data exchange hold game-changing promise for adaptive oversight. Live hydrological tracking, glacier surveillance, and public climate repositories can sharpen alerts and policy agility. Still, tech progress needs paired with openness and data uniformity for fair access across areas (Wester et al., 2019).

Lastly, closing science-policy divides is essential. Deepening ties among researchers, officials, and communities enables joint knowledge creation and data-driven adaptation. Through promoting broad involvement, funding autonomy, cross-border ties, and data clarity, polycentric governance can strengthen resilience in the Eastern Himalayan socio-ecological landscape.

8. Conclusion

The Eastern Himalayan area, especially Northeast India, exemplifies the complex interplay of governance and climate resilience in delicate mountain settings. As outlined in this

chapter, regional climate vulnerability stems not just from hydro-climatic changes or environmental decline, but from institutional setups, power dynamics, and policy structures. National tools like the NAPCC and NDCs, together with State Action Plans on Climate Change, form a vital policy foundation; however, their success hinges on tailored execution, cross-department collaboration, and genuine community involvement. Cases from Assam, Arunachal Pradesh, and Sikkim show that strong adaptive governance thrives where local participation, institutional creativity, and ecological balance intersect.

Inclusive methods and cross-border partnerships stay essential for enduring resilience. Traditional bodies, native ecological insights, and localized decision-making build trust and flexibility at community levels. At the same time, linked river systems and ecosystems call for robust regional talks, open data sharing, and joint basin management. Absent these joint efforts, isolated national initiatives may erode wider ecological health.

Moving forward, sustainable progress in the Eastern Himalayas demands weaving polycentric governance into climate strategies, boosting financial devolution, developing digital climate monitoring tools, and nurturing science-policy links. By merging grassroots ingenuity with regional and global cooperation, the area can advance a more equitable and resilient path to mountain development under climate stress.

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10

Ecology, Economy and Ethics in Eastern Himalayas: Tracing the Trajectory of Conflict and Coexistence to Date

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ABSTRACT

Human history has witnessed the Himalayan Mountain range carrying snow as its eternal symbol of beauty, mystery, magic and life to this date. It has undergone rich cultural, social, economic, and environmental changes throughout time. While it has served people's purpose well, it is one of the most vulnerable regions on earth. The existing studies have explored biodiversity, climate issues, geopolitical security concerns in the region but researchers have paid limited attention to the ethical dimensions linking ecology and economy. This paper shall attempt to study the Eastern Himalayas in terms of ecological conflict which are rooted in historical and contemporary development practices mandating economy over ethics. It will examine the conflicts as well as coexistence among local communities regarding environmental ethics through a theoretical perspective and an ethical framework. This paper will explore the dilemmas of a practical approach and responsibility towards climate change in this region. The title itself carries the essence of the subject matter showcasing the journey of survival and development from the colonial period till this date.

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It shall explore indigenous knowledge of tribal communities with a shift of discourses such as traditional knowledge systems are often disrupted due to modern viewpoints. The study includes qualitative and thematic analysis of historical documents, academic research papers, policy reports and various reliable reports to examine the relationship between ecology, economy and ethics in the Eastern Himalayas. This paper will be an inclusive approach to unfold the complexities of implementing policy and governance integrating ecological indigenous knowledge along with the ethical consideration of mindsets in changing dynamics of power and politics.

Keywords: *Eastern Himalayas, Environmental Ethics, Ecological Conflict, Indigenous Knowledge, Development Politics*

1. Introduction

The Eastern Himalayan region is extended from the Teesta River in the west to the easternmost reaches of the Himalayas, receiving high rainfall and with dense evergreen forest coverage throughout the foothills, tropical, subtropical, savanna, tundra, and alpine forests in the moist environmental condition with complex rugged topography. This region consists of Sikkim, the Darjeeling area (West Bengal), Arunachal Pradesh, the hills of Assam, Nagaland, Meghalaya, Manipur, Mizoram, and Tripura. It represents one of the most ecologically and culturally diverse mountain systems in the world and is home to various globally threatened species, including Asia's three largest herbivores, i.e., the Asian elephant, the greater one-horned rhinoceros, and the wild water buffalo, as well as several large birds such as vultures, adjutant storks, and hornbills, etc. (WWF). Being a pharmacological goldmine, the ecological health of this region is crucial for the whole Himalayan ecosystem, making it strategically significant and sensitive. This physiography historically shaped settlements, agriculture, cultural practices, and ethics of policymaking for the development purposes in different ways because, along with the rich topographical diversity, these places are vulnerable to natural hazards like floods, landslides, land erosion, etc. The people of that region did not manage resources in a technical sense, but they live with spiritual beliefs systems in an ancestral order (Singh 2001: 2970-2973). This complexity even put challenges for the

colonial expansion as technical obstacles during the nineteenth century. Ecology and ethical questions have always been related to each other, as they eventually have a great impact on the economy of a particular region. Historical evidence has shown that with time the British Empire transformed this place with reserved and protected forest acts inspired by German models with the hidden intention of commercial extraction of natural resources and rare and expensive agricultural products for military logistics (Singh 2001: 2968). The sudden shift towards sophisticated commercialization actually created environmental issues degrading soil quality and biodiversity. Throughout time, the selected trade routes were even considered as border concerns and the other conservation policies excluded local communities revealing moral paradox and also the development related projects brought ethics to the forefront of debates through activists, scholars and concerned local residents. It is facing continuous negotiations between ecological fragility and economic ambitions. This paper explores these history, ideas, policies, treaties, and justice to provide a mutual ethical ground to work on for the betterment of the trajectory till date.

2. Literature Review

The Eastern Himalayas have been studied through disciplines such as environmental concerns, rich biodiversity, history, political ecology, anthropology and developmental studies. Different scholars have examined conservation, indigenous knowledge systems, migration and border security. However, these studies explore these themes separately. This literature review unfolds the major scholarly contribution in this field.

B. P. Singh in his paper "The Eastern Himalaya: Wetlands, Forests and Beliefs" talks about the rich physiography of the region with abundance of natural resources which could create economic growth for those regions. The author also explores the lifestyle and culture of the local community and their traditional knowledge of resources which have been changed through time due to conflicts around their lives. "Biodiversity in the Eastern Himalayas: Status, trends and vulnerability to climate change; Climate change impact and vulnerability in the Eastern Himalayas – Technical report 2" is a report published by Nakul Chettri, Eklabya Sharma, B Shakya and Rajesh Thapa which discusses fragility of mountains and its ecology

particularly in the Himalayan ecosystem. The threatened biodiversity is the main theme for the report analysis. They explore 'The International Centre for Integrated Mountain Development (ICIMOD)', 'Programme of Work on Mountain Biodiversity' , 'Convention on Biological Diversity' etc. for a better understanding of challenges and probable opportunities to grab soon. The World Wildlife Fund has provided a blog post explaining the flora and fauna of the Eastern Himalayan region along with fragility of the environment in that particular area. The blog post elaborated the climate change issues and the related threats over biodiversity in that highly sensitive area. These studies collectively emphasize fragile ecosystems along with biodiversity richness. They highlight conservation challenges and climate vulnerability with limited discussion on the ethical dimension that shapes this particular region.

"Integrating ethnobiological knowledge into biodiversity conservation in the Eastern Himalayas" by Alexander R. O'Neill, Hemant K. Badola, Pitamber P. Dhyani and Santosh K. Rana and "Origins and Migrations in the Extended Eastern Himalayas" by Toni Huber and Stuart Blackburn elaborate on descriptions of the hill peoples of the Eastern Himalayan region. They address a serious challenge of indoor and outdoor migration that opens up different types of hypotheses. It covers local oral narratives apart from research papers and scholarly articles in journals about people. A paper titled, "International relations and the Himalaya: Connecting ecologies, cultures and geopolitics" Alexander E. Davis, Ruth Gamble, Gerald Roche & Lauren Gawne talks about transformation of International Relations in The Himalayas throughout time. It covers the diplomatic relations with systems of state making and trading patterns in the contemporary environment. Apart from these the paper also tries to provide a new Himalayan research agenda for International Relations in the region.

"The Routledge International Handbook of Himalayan Environments, Development And Wellbeing" by Ben Campbell, Mary Cameron and Tanka Subba portray the interaction between local community and forest environment, use of science and technology for the development such as digital infrastructure, climate change in Himalayan Mountain region. They connect the historical case studies in community reserved areas. Sanjib Baruah in his article named "Whose River Is It Anyway? Political

Economy of Hydropower in the Eastern Himalayas" discusses the water disputes in the region. This exploration includes vulnerable conditions of the environment along with political risks against livelihood patterns. It is more inclined towards the solution than the single problem statement. These two works present hydropower infrastructure and geopolitical aspects. They rarely explore ecological subject matter and questions of ethics and justice.

In the above-mentioned readings on the Eastern Himalayan ecosystem, limited emphasis on ethical background in relation to ecology and development have been observed. Although they contribute to understanding biodiversity, vulnerable climate actions, livelihood of natives and political transformation. These studies mostly examine these themes separately leaving insufficient analysis of how ethical frameworks can explain the conflict and coexistence in a historical perspective. It is undeniable that there are seldom attempts to analyze these challenges. Therefore, this paper participates in the discussion about coexistence which is understood here as the ability of communities to interact without creating disruption at large in the ecology and conflict in the Eastern Himalaya for ecological health and ethical knowledge at the same time.

3. Methodology

This paper has used qualitative methods to capture the real essence of the region. Academic papers, peer-reviewed journals, historical records, policy documents and environmental reports published by renowned international organisations and scholarly works from various sites are secondary sources for attempting this paper. The analysis covers the period from colonial intervention i.e. the nineteenth century to contemporary developments. While writing this paper, ecology is discussed in terms of the relationship between human and nature, economy refers to the patterns of resource use for development purposes and ethics refers here to the moral principles guiding decision making for a collaborative understanding. It is an attempt for a theoretical lens of environmental ethics and political ecology regarding the conflict of coexistence in the region examining the historical background or storyline as a whole focusing on three interrelated themes such as ecological change, economic development and environmental ethics. This interdisciplinary

research focuses on thematic analysis rather than quantitative aptitude such as how historical decisions, state policies, economic interests and power relations shape conflict in Eastern Himalayas. It does not rely on primary fieldwork or direct interviews but focuses on the relationship between human communities and natural resources.

4. Discussion

The central argument of this paper is that ecological conflicts in the Eastern Himalayas have emerged from the historical and current prioritization of economic strategies over environmental ethics. The ecology of the Eastern Himalayan region has the capacity to influence the lives of people living in that area, transcending all the difficulties and in multifarious ways across the parts of Northeast India, Bhutan, Nepal, and the Tibetan Autonomous Region of China. Historically this region is considered a meeting ground for civilizations, a corridor of biodiversity, and sacred ground for medicinal plants, along with high demand in the economic market for natural resources. This region provides a genetic vault for endangered flora and potential pharmaceutical breakthroughs (Hara 1966: 5). According to J. Baird Callicott, these ethical responsibilities extend beyond human society to native communities and moral obligations at large. However, colonial and postcolonial development initiatives have generated economic opportunities but also have disrupted traditional sustainable approaches. Therefore, this region requires a huge collective initiative from the countries advocating the policy of common but differentiated responsibility regarding the contribution to the developmental agendas targeting to create a periodic mechanism of accountability in a transparent framework to work better than the binding commitments in achievement of goals, provided a proper appreciation of the needs and aspirations of the stakeholders is made. There should be a mutual ground for ecology, ethics and economy which strongly demands a layered understanding of the historical storyline about conflict and coexistence influenced by colonial exploitation, post-colonial anxiety, political power structure, and resistance from indigenous communities in contemporary climate change issues before it is too late.

5. Historical Background of Conflict and Coexistence

The Eastern Himalayas fosters a great range of biodiversity with the presence of iconic species. This diversity of species itself plays a key role in maintaining the balance in the region apart from the climatic variability. But the geographic fragility cannot be underestimated in the region. Indigenous communities such as Mishings, Adis, Nyishis, Lepchas, Bodos, Monpas, and others have been worshiping nature, rivers, protecting sacred grooves and the mountain as ancestors from ages (Huber & Blackburn 2012) . The agricultural patterns are also environment friendly and the customary laws play a significant effort to combat natural challenges directly or indirectly improving capacity building framework (Campbell et al. 2026: 650-680). This region was considered a resource rich zone by the British colonial expansionists as they recognized the probability of economic growth. After 1774, the polity, economy and ecology started to change gradually in the region. At the core of that commercial system the relationship among Bengal, Nepal, Bhutan, and Sikkim with Tibet was crucial for the economy. But in the colonial period new outlets for British manufactured goods aimed to penetrate the lucrative markets of China and Central Asia. Tibet was the epicenter for trade in the vast mineral resources especially its gold and salt deposits in the trading community of the Kham region in western Tibet emerged as a powerful force influencing the polity and economy in the Eastern Himalayan region. The state officials and people from monasteries took part in monopolization of routes in Nepal, Bhutan and in Sikkim. Because these shifts redefined nature as an economic asset rather than shared ecological space. In the eighteenth and nineteenth century, some of the conflicts with Britishers changed the market and political scenario such as annexation of Darjeeling, Anglo Chinese convention, Treaty of Betarwati etc. However, this intervention created new communication networks along with expanding commercial possibilities providing a wider outlet. The colonial rule also provided the notion of reserved forests which gave the tag of criminal activity to the traditional agricultural practices and encroachment. Ironically, the large infrastructural development was much more destructive to nature than subsistence jhum as an age long agricultural practice (Singh 2001). Therefore, through this historical analysis it is said that the colonial

expansionists misplaced the ethical base for materialistic economic growth creating the foundation for contemporary ecological conflict. The old practices of conservation of local communities are actually epistemologies embedded in oral narratives which are collective and experimental. However, modern scientific rationality, bureaucratic hierarchy often dismisses these 'primitive structures'. So the answers would be in decolonization of development where mountain specific policies should be in focus.

6. Contemporary development and ethical dilemmas

With time, the eastern himalayan region became a hotspot for hydroelectric projects, threatening vulnerable areas for border security, oil refineries, highways which started to generate modern socio-ecological conflicts (Chettri et al. 2010: 1-15). For example, scholars have argued that large dams on Subansiri and Siang rivers became a threat to seismic safety, fish migration, agricultural cycles, and displacement of riverine communities (Baruah 2012: 41-52). These infrastructures indicate how development led interventions often generate ecological costs when community knowledge is excluded from decision making. Economic prosperity is the key element to the quality of life and is also necessary for the region to be competitive in the global economy. But apart from this, the notion of coexistence requires government intervention in the distribution of resources to empower people with equal opportunities and ensure merit in the region instead of limiting opportunities for growth to a particular class, gender, race or religion. Hence, there should be constitutional laws for normative commitment to holistic ecological integrity yet growth. The development models of Bhutan and North East India provide specific initiatives for institutionalisation of ethics and accountability as an alternative embodiment of conservation practice. Even the valley areas are dependent upon the environmental condition of the mountains because when the snow melts they deeply affect the densely populated valleys which make them vulnerable to disasters. Eco-tourism is addressed as an alternative sustainable economic goal but the diversity of the local communities often work as obstruction in balancing livelihood diversification with carrying capacity limits. Without careful regulation, mere environmentally friendly labels can degrade the situation

through social inequality. These contemporary development projects often reproduce earlier tensions by prioritizing economic growth while keeping the vulnerability of ecosystems at stake. Hence, it is very much important that ethical coexistence requires recognizing indigenous sovereignty rather than romanticizing indigenous wisdom as a whole.

Taken together these examples represent that conflict and coexistence in this region are shaped by ecology, economy and ethics. Natural disasters are not only ecological phenomena but also create socio-cultural and political crises due to unplanned development models. The dominance over nature is the key element of ethical dilemmas in recent years. In the contemporary world, growing activism, movements and research make clear viewpoints around civic consciousness of Eastern Himalayan ecosystem conservation plans. Legal intervention upon mining activities creates ecological tension enforcing labor exploitation, illegal resource extraction and unsustainable regulations on policies. Theoretically the decisions regarding development are influenced by political scenarios in the particular regions where it depended upon national security concerns, changing market forces in the world order, and global capital flows. Analytical information has always been used for stability on the ethical background. Therefore, the Eastern Himalayas are not only a specific geographical space but it is a dynamic and fragile element in the environment aligning with tradition and modernity, extraction and conservation, power and participation accelerating change in a vibrant way.

7. Conclusion

This paper discussed the ecology, economy, and ethics in the Eastern Himalayas, which portrayed the complex picture of disruption and renewal of the natural resources. It showed how colonial expansionists misplaced the ethical knowledge base for economic profit among indigenous communities against contemporary climate demands for change (O'Neill et al. 2017: 10-14). Afterwards, the post-colonial era craved development in such a way that coexistence in these regions became difficult without sustainable governance, community forestry, organic agriculture, and transboundary cooperation. This paper showed the exact trajectory to date with a clear picture of human–nature negotiation which required collaborative learning and

methods in policymaking and international diplomacy for a transformation (Davis et al. 2020: 15-35). Apart from these issues, the region is still rich in the coexistence of indigenous communities across Assam, Arunachal Pradesh, Sikkim, and adjoining hill regions showing resilience through adaptive practices in the contemporary world. The ethical dilemma is that redefining development in the particular regional background is crucial because it has to be against the utilitarian economic model. It also explored that negotiations are always influenced by power and politics but with proper consciousness preservation and aspiration can go hand in hand. Thus, there should be a development model beyond GDP-driven metrics because it should be about ethical wealth creation through Gini Coefficient that needs to be taken care of by societies and the governments at large. Apart from the geographical prosperity, the local communities belonging to any stratum, deserve a good life, need to have rights to make it better and be able to use means to achieve something prosperous. Economic prosperity combined with ecological balance with the foundation of ethical knowledge can have a synergistic effect on the growth engine of the Eastern Himalayas.

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11

Political Ecology of Hydropower Development in Northeast India

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ABSTRACT

Northeast India has been identified as a major frontier for hydropower expansion due to its vast river systems and steep topography. However, the proliferation of large hydropower projects in this ecologically fragile region has generated significant debate concerning their environmental, social, and governance implications. This chapter examines hydropower development in Northeast India through the lens of political ecology. Drawing on the cases of the Subansiri Lower Hydroelectric Project, Dibang Hydropower Project, and Teesta III Hydroelectric Project, the chapter argues that hydropower development in Northeast India represents a climate governance paradox in which decarbonisation objectives coexist with environmental risks and governance challenges.

Keywords: *Hydropower, Renewable Energy, Environment, Northeast India, Dams*

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1. Introduction

Governments and international institutions have increasingly prioritised the transition toward renewable energy sources to reduce greenhouse gas emissions and achieve decarbonisation. India has set ambitious, updated climate targets under the Paris Agreement to achieve net-zero emissions by 2070, aiming for 500 GW of non-fossil fuel capacity and reducing GDP emissions intensity by 45% by 2030 (Government of India, 2022). In this context, renewable energy expansion has become central to India's climate mitigation strategy, and hydropower plays a significant role in stabilising electricity supply and supporting grid flexibility. Within India's renewable energy strategy, Northeast India has emerged as a critical site for hydropower development. The region contains some of the most powerful river systems in South Asia, including the Brahmaputra River and its tributaries such as the Subansiri River and Dibang River. According to estimates by the Central Electricity Authority (2020), the hydropower potential of Northeast India exceeds 60,000 MW, representing nearly forty percent of the country's total hydroelectric capacity (Thakur, 2023). However, the expansion of hydropower infrastructure in the region has generated increasing controversy. "Green energy" infrastructure often presents its own ecological and geopolitical vulnerabilities. Northeast India forms part of the Eastern Himalayan biodiversity hotspot and is characterised by fragile mountain ecosystems, high seismic activity, and complex socio-cultural landscapes inhabited by indigenous communities. Large dam construction in such environments raises concerns regarding ecological degradation, geological vulnerability, and social displacement.

This chapter examines hydropower development in Northeast India from a political ecology perspective, focusing on the relationship between renewable energy expansion and environmental sustainability in the region. The study explores the environmental, socio-economic, and governance implications of hydropower expansion and assesses whether it represents an effective climate mitigation strategy or an emerging ecological risk. The analysis is based on case studies of the Subansiri Lower Hydroelectric Project, the Dibang Multipurpose Project, and the Teesta Stage III Hydroelectric Project, which highlight broader

tensions between climate mitigation goals and ecological sustainability in the region.

2. Hydropower: A Political Ecology Framework

The Government of India has consistently prioritised hydropower development in Northeast India as part of its broader strategy to expand electricity generation and enhance national energy security. This emphasis must be situated within wider political-economic processes. As argued by David Harvey (2005), large-scale infrastructure projects are deeply embedded in circuits of capital accumulation and territorial integration. In the Indian context, the incorporation of the Northeast into national energy grids and strategic imaginaries reinforces state presence in a historically peripheral region (Baruah, 2005). The proposal of approximately 165 large dam projects across the region highlights the scale at which hydropower has been envisioned as both an economic and geopolitical project. Historically, hydraulic interventions in India were shaped by shifting state priorities. During the colonial period, such interventions were primarily geared toward revenue extraction through irrigation expansion and flood control. These efforts exemplify what James C. Scott (1998) conceptualises as a technocratic vision of statecraft, wherein complex ecological systems are simplified and reordered to enhance administrative legibility and control. In the post-independence period, hydropower development acquired renewed significance. As Kakati (2017) notes, large dams were viewed as critical instruments for achieving energy security, expanding irrigation, and mitigating floods. Jawaharlal Nehru famously characterised dams as the "temples of modern India," symbolising technological progress and sovereign mastery over nature. Scholars such as Partha Chatterjee (2004) have interpreted this phase as the consolidation of a state-centric development paradigm, wherein technocratic planning institutions assumed authority over natural resource governance. Consequently, dam construction not only facilitated economic development but also centralised decision-making processes, frequently marginalising local communities and disregarding indigenous ecological knowledge systems. Over time, however, the developmentalist narrative surrounding large dams has come under sustained critique. Concerns regarding population displacement, ecological degradation, and the uneven

distribution of benefits have generated widespread resistance to large infrastructure projects. By the late twentieth century, this critique had significantly eroded the earlier consensus on dam-led development. The report of the World Commission on Dams (2000) marked a critical turning point in global debates. While acknowledging the substantial contributions of dams to electricity generation, irrigation, and water storage, the Commission highlighted systemic failures in assessing environmental and social impacts. It documented large-scale displacement and ecological damage, often accompanied by inequitable benefit distribution. In response, the Commission advocated a new decision-making framework centred on participatory governance, transparency, and equitable cost-benefit sharing. Although contested, these recommendations reshaped global policy discourse and encouraged more cautious and inclusive approaches to hydropower development.

Within India, these evolving debates have informed a gradual recalibration of hydropower policy. Heightened environmental scrutiny and social mobilisation have prompted a partial shift from large, multipurpose dams toward smaller, single-purpose hydroelectric projects. Nevertheless, hydropower continues to occupy a central position in India's renewable energy strategy, particularly in regions with substantial untapped riverine potential such as the Northeast. Yet, hydropower expansion in Northeast India unfolds within a highly fragile ecological and geological context. The Eastern Himalayan region is characterised by seismic instability, steep topography, intense monsoonal rainfall, and high sediment loads, all of which complicate large-scale infrastructure development (Vagholikar & Das, 2010). These vulnerabilities are further compounded by climate change. According to the National Climate Vulnerability Assessment by the Ministry of Science & Technology (2021), states such as Assam, Mizoram, and Arunachal Pradesh rank among the most climate-vulnerable regions in India. These conditions raise serious concerns regarding dam safety, disaster risks, and long-term ecological sustainability, particularly in the context of extreme weather events and shifting hydrological regimes.

In the contemporary period, hydropower has been reframed through the lens of climate mitigation, reflecting the logic of ecological modernisation. Theorists such as Arthur P. J. Mol

argue that environmental challenges can be addressed through technological innovation and institutional reform without fundamentally transforming existing economic systems (Mol & Spaargaren, 2000). Within this paradigm, hydropower is promoted as a form of "clean energy," enabling states to pursue low-carbon transitions while sustaining economic growth (IPCC, 2022). However, this framing often obscures the localised environmental and social costs of dam construction, particularly in ecologically sensitive regions. A political ecology perspective moves beyond the binary of hydropower as either a climate solution or an ecological threat. Instead, it conceptualises hydropower as a politically embedded process that simultaneously advances decarbonisation goals while producing uneven socio-ecological outcomes. As Paul Robbins (2012) emphasises, environmental outcomes are shaped by historically situated power relations, institutional arrangements, and competing knowledge systems rather than purely technical considerations. From this standpoint, large dams are not neutral infrastructures but political interventions that redistribute resources, reconfigure territorial control, and generate differentiated impacts across social groups. Building on this analytical framework, this paper conceptualises hydropower development in Northeast India as a form of green developmentalism, that is, the strategic deployment of climate mitigation discourse to legitimise large-scale, state-led infrastructure expansion in ecologically fragile and politically peripheral regions. This perspective highlights how ostensibly "green" energy transitions may reproduce existing inequalities by externalising environmental and social costs onto marginalised landscapes and communities, thereby calling into question the distributive justice of contemporary climate governance.

3. The Hydropower–Development-Ecology Contestation in Northeast India

Hydropower development in Northeast India represents a critical intersection between national development priorities and ecological sustainability. The expansion of dam infrastructure has also sparked intense debates about environmental degradation, the displacement of local communities, and the long-term sustainability of large-scale river interventions. The cases of the Subansiri Lower Hydroelectric Project, the Dibang Multipurpose

Hydropower Project, and the Teesta Stage III Hydroelectric Project demonstrate how hydropower development in the Eastern Himalayas simultaneously embodies climate-mitigation aspirations and ecological risks.

The Subansiri Lower Hydroelectric Project represents one of India's largest hydropower initiatives. The project was approved in 2003 and implemented by the National Hydroelectric Power Corporation. It was designed as a run-of-the-river scheme with an installed capacity of approximately 2,000 MW and an expected annual generation of more than 7,400 GWh of electricity. From the perspective of the Indian state, the project is framed as contributing to renewable energy generation, grid stability, and regional development. However, its implementation has generated sustained contestation, particularly in downstream Assam. While official project documents emphasise regulated water flow and minimal downstream disruption, local organisations such as the All Assam Students' Union, the Krishak Mukti Sangram Samiti and NGOs have raised concerns regarding downstream flooding, sediment disruption, and ecological instability (Bhattacharyya, 2020). Rather than treating these claims as definitive, a more rigorous approach is to situate them within competing knowledge frameworks. The Expert Group Committee constituted by the Government of India (2011) in 2011 identified several technical uncertainties, including issues related to seismic safety, sediment management, and downstream hydrological impacts. These findings suggest that concerns regarding flood risk and river morphology are not merely speculative but grounded in recognised scientific challenges, even if their magnitude remains debated. Similarly, estimates regarding submergence and ecological impact vary across official and independent assessments, reflecting broader disagreements over cumulative basin-level impacts (Baruah, 2012). Importantly, the project is located in Seismic Zone V, the highest seismic risk category in India. While engineering designs incorporate safety measures, the long-term implications of large dam infrastructure in a tectonically active region remain subject to ongoing scientific debate. Past incidents of sudden water releases from regional hydropower projects such as Ranganadi and Kopili have further shaped public perceptions of risk, illustrating how experiential knowledge informs local resistance alongside formal expertise. From a political ecology

perspective, the Subansiri case demonstrates how hydropower projects become arenas of contested expertise, where state agencies, scientific bodies, and civil society actors advance competing interpretations of ecological risk and development necessity.

The Dibang Multipurpose Project with a projected capacity of approximately 2,880–3,000 MW and a dam height exceeding 270 metres. While the state frames the project as a multipurpose intervention combining electricity generation and flood moderation, its social and ecological implications have generated significant debate. A central limitation of conventional analyses is the tendency to frame indigenous communities primarily in terms of displacement. In the Dibang context, the Idu Mishmi articulate a more fundamental critique rooted in distinct ecological worldviews and customary land relations. The proposed reservoir is expected to submerge more than 4,000 hectares of land and affect over 40 villages, potentially displacing hundreds of families belonging primarily to the Idu Mishmi indigenous community (Linggi, 2025). For these communities, land and rivers are not merely economic resources but form part of a relational landscape involving cultural identity, subsistence practices, and spiritual significance (Aiyadurai, 2016). Sacred groves, river systems, and forested landscapes are embedded within ritual and cosmological frameworks that do not align with the extractive logic of large-scale infrastructure. This creates a deeper form of conflict than is captured by displacement statistics alone. Environmental impact assessments have been criticised for insufficiently incorporating such knowledge systems, instead privileging technocratic and quantifiable metrics of impact. Ecologically, the Dibang basin is characterised by dense forest cover and high biodiversity, forming part of the Eastern Himalayan biodiversity hotspot. The Dibang basin contains extensive forest ecosystems covering more than 70 per cent of the region, supporting rich biodiversity and important bird habitats (Ministry of Environment, Forest and Climate Change, July 2016). Official assessments acknowledge significant forest diversion and landscape transformation, while independent studies highlight risks of habitat fragmentation and disruption of riverine ecosystems (Vagholikar & Das, 2010). These concerns are compounded by the region's susceptibility to landslides, seismic activity, and climate-induced hydrological variability.

The Teesta Stage III Hydroelectric Project in Sikkim provides a critical case for understanding the relationship between hydropower infrastructure and climate-induced hazards. With an installed capacity of 1,200 MW, the project forms part of a cascade of dams along the Teesta River. Hydropower expansion has been central to Sikkim's economic strategy, with the state possessing an estimated hydropower potential of nearly 8,000 MW (Dukpa et. al. 2018). However, the concentration of multiple dams along the same river system has raised concerns regarding cumulative environmental impacts. The October 2023 glacial lake outburst flood (GLOF), severely damaged the dam and caused widespread downstream destruction (Institute of energy and the environment, 2024). It has been widely interpreted as evidence of the vulnerability of Himalayan hydropower infrastructure. Climate change is accelerating glacial retreat across the Himalayas, leading to the expansion of unstable glacial lakes and increasing the probability of high-magnitude flood events (IPCC, 2022). These vulnerabilities are closely tied to the epistemic and institutional frameworks underpinning hydropower development. The concentration of multiple dams within a single river basin further amplifies these risks. The Teesta III project has also generated significant socio-political resistance, particularly among local communities, including indigenous groups such as the Lepchas (Lachenpa, 2025). These communities have articulated concerns over displacement, loss of access to common resources, and the cultural significance of the Teesta River. From a political ecology perspective, such resistance is not merely reactive but constitutes a form of environmental politics that challenges dominant development narratives.

Taken together, these cases suggest that hydropower in Northeast India cannot be understood simply as a trade-off between climate mitigation and ecological risk. Instead, it represents a form of "green developmentalism" in which low-carbon infrastructure is embedded within existing power structures, often reproducing patterns of marginalisation and environmental inequality. These projects may be interpreted as what Scot (1998) views as a technocratic vision of statecraft, that privilege abstract technical knowledge over lived social realities. Instruments such as Environmental Impact Assessments (EIAs) and techno-economic feasibility studies tend to privilege expert-

driven, formalised knowledge systems, often marginalising local, experiential understandings of river dynamics, seasonal variability, and risk. This epistemic hierarchy contributes to the underestimation of uncertainty and the depoliticisation of environmental risk. The evidence from Northeast India suggests that hydropower should be understood not simply as a technological solution but as a politically embedded form of environmental transformation, shaped by competing claims over development, ecology, and justice. From the perspective of the central government, hydropower projects fulfil several strategic objectives of expanding renewable energy production, promoting regional economic development, and strengthening national energy security. Although smaller hydroelectric plants in Arunachal Pradesh have successfully registered for carbon credit mechanisms, the large dams have not yet widely secured green infrastructure financing. Additionally, ecological and social realities complicate this developmental narrative. Hydropower expansion often generates conflicts related to displacement, resettlement, and the erosion of traditional resource management systems. Local resistance to hydropower projects has emerged as a major political issue across the region. Large dams significantly reshape river ecosystems by altering sediment transport, fragmenting aquatic habitats, and disrupting fish migration patterns. Given that the Eastern Himalayas constitute a globally recognised biodiversity hotspot, such environmental transformations may have long-term ecological consequences.

4. Conclusion

Hydropower development in Northeast India occupies a central role in India's renewable energy strategy and climate mitigation agenda. However, its expansion across the ecologically fragile Eastern Himalayan region reveals that it cannot be understood simply as a transition toward clean energy. Instead, hydropower emerges as a politically embedded process that generates significant ecological, social, and climatic risks. This paper has advanced three key arguments. First, hydropower is legitimised through the discourse of climate mitigation and Ecological Modernisation, which frames large dams as essential to low-carbon development while often obscuring uneven social and environmental costs. Second, hydropower projects reconfigure state–society relations by centralising control over

river systems and marginalising local communities, particularly indigenous groups whose knowledge systems remain inadequately recognised. Third, the ecological and climatic conditions of the Eastern Himalayas introduce structural uncertainties that challenge the long-term sustainability of large-scale hydropower, with events such as glacial lake outburst floods indicating systemic rather than exceptional risks. The cases of the Subansiri Lower Hydroelectric Project, Dibang Multipurpose Project, and Teesta Stage III Hydroelectric Project illustrate how hydropower development produces uneven outcomes across power, distribution, knowledge, and risk. While benefits accrue at national and regional levels, ecological disruption, displacement, and vulnerability are disproportionately experienced at the local scale. Theoretically, the paper contributes to Political Ecology by conceptualising hydropower as a form of green developmentalism, in which climate mitigation narratives legitimise large-scale infrastructure while masking their embeddedness in unequal power relations. This chapter demonstrates that climate mitigation projects are not merely technical solutions but contested processes that can reproduce environmental inequality. Addressing this requires more integrated, participatory, and context-sensitive approaches to energy transitions, particularly in ecologically vulnerable regions such as the Himalayas.

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12

When Cooperation Frays: Securitization and Institutional Survival in the Himalayas

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ABSTRACT

This chapter examines how geopolitical securitization shapes ecological cooperation in the Himalayan region. It argues that while heightened India-China tensions constrain transboundary cooperation, they do not produce uniform breakdown. Instead, cooperation exhibits divergent trajectories depending on institutional form. Drawing on a comparative analysis of two cases: a) bilateral river data sharing of the Brahmaputra and b) multilateral engagement through the International Centre for Integrated Mountain Development (ICIMOD), the chapter shows how narrow, obligation-based arrangements are more vulnerable to breakdown under prolonged security stress, whereas epistemic institutions embedded in multilateral networks display greater organizational persistence. Hydrological data sharing on the Brahmaputra illustrates how cooperation can lapse quietly through non-renewal of agreements in a securitized environment. By contrast, ICIMOD's continued functioning demonstrates institutional survival.

Keywords: *India, China, Hindu Kush-Himalaya (HKH), Transboundary Water Governance, ICIMOD*

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1. Introduction

The Eastern Himalayas (EH) which is a region sandwiched between India and China contains one of the most diverse ecosystems in the Indian subcontinent (Hore and Uniyal, 2008). Its forests provide numerous ecosystem services to hundreds of millions of people well beyond their geographical confines. (Banerjee et al., 2022) and its rivers serve as the lifeline for provinces and countries downstream.

Over the years, state-to-state tensions have also led to the militarisation of the region (Davis et al. 2020). India and China have engaged in multiple border skirmishes fuelled by 'the absence of a demarcated border and lack of consensus as to where the LAC[2] lies' (Crisis Group Report, 2023). Such securitisation spills over to environmental governance, 'like data sharing related to water' (Sun & Awale, 2025). During the Doklam crisis, for instance, China was accused of weaponization of water (Wuthnow, 2017), a phenomenon we will examine in more detail. As a result, environmental governance in the Himalayas is constrained by both material limitations and political sensitivities, making sustained transboundary cooperation difficult even where ecological interdependence and necessity of cooperation are widely recognised.

There have also been concerns about paucity of data with the fourth Inter-governmental Panel on Climate Change (IPCC) Report published in 2007, identifying the whole Himalayan region as a 'black hole for data, with no consistent long-term monitoring of the region' (Bhushal, 2020). Under such conditions, the ICIMOD, which is an intergovernmental epistemic organisation originally set up in 1983, comprising eight Regional Member Countries (RMCs): Afghanistan, Bangladesh, Bhutan, China, India, Myanmar, Nepal, and Pakistan, has been crucial for environmental governance in the Himalayan region.

The puzzle examined in this chapter matters because the EH sits at the intersection of intensifying geopolitical rivalry and accelerating ecological vulnerability. Understanding how cooperation behaves under such conditions is analytically important. By comparing bilateral river data-sharing with multilateral engagement through ICIMOD, this chapter

2 The Line of Actual Control (LAC) is the disputed de facto boundary separating Indian and Chinese controlled territories.

argues that ecological governance under rivalry is not simply determined by political tension but mediated by institutional design. Here, ICIMOD is presented as a case of 'institutional survival' which refers to the ability of an institution to maintain organisational & procedural continuity under adverse political conditions. This is opposed to 'cooperative resilience,' which not only implies continuity but also sustained or meaningful cooperation among member states.

This chapter proceeds in three parts. The first section examines bilateral river water data sharing between India and China, analyzing how information flows related to transboundary rivers have become increasingly securitized. The second section turns to the ICIMOD as a contrasting case, showing how multilateral, epistemic cooperation in the Himalayan region has persisted in constrained but resilient forms despite similar political pressures. The final section brings these cases together to explain their divergent trajectories, arguing that differences in institutional design, scope, and modes of cooperation help account for why some forms of ecological cooperation endure under securitization while others quietly lapse.

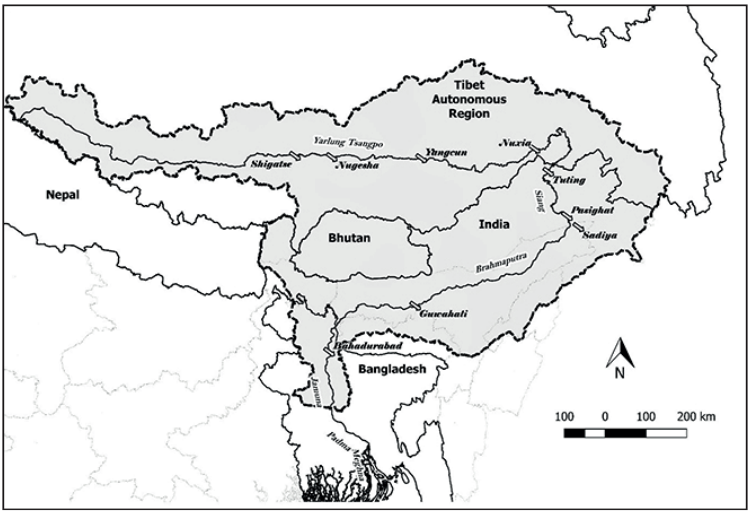
2. River Water Data Sharing: A Case of Information Securitization

The Brahmaputra, known upstream in China as the Yarlung Tsangpo, forms one of Asia's most hydrologically significant transboundary river systems. The river is the largest by annual discharge and the fourth largest by water flow in the world (Ray et al., 2015). Approximately 50.5% of the total basin area lies in China, followed by India (33.6%) (Barua et al., 2025), which makes it a substantial transboundary river system.

Many scholars have warned about the possibility of Brahmaputra's securitization between upstream China and lower riparian India (Chellaney, 2011; Zhang, 2016). Experts have warned that China's dam construction on the Yarlung Tsangpo may affect lean-season flows, disrupt sediment and ecological cycles, and increase downstream vulnerability in India's northeastern states (Manhas & Lad, 2024). There have also been concerns about China's river water diversion projects, which it has historically implemented in the Yangtze River basin under the South–North Water Transfer Project (SNWTP). Although China has claimed that it doesn't plan to divert waters at the Brahmaputra &

that 'water downstream will not be cut' (Saikia, 2022), its dam construction projects in the Tibetan Autonomous Region (TAR) at Gyatsa, Jieuxu, Langzhen, Zangmu, and Zhongda (Rao, 2011) have been interpreted by some scholars as an imminent threat to India's water security (Mahapatra & Ratha, 2016).

Currently, hydrological data sharing between China and India operates through seasonal memoranda that provide discharge information from three primary Chinese gauging stations: Nugesha, Yangcun, and Nuxia (Bandyopadhyay et al., 2020). Crucially, Nuxia which is the southernmost station, is still located well upstream of the Great Bend, before the river traverses its most hydrologically dynamic stretch. By contrast, the first Indian gauging stations, i.e., Tuting & Pasighat in Arunachal Pradesh lies approximately 320 km & 530 km downstream of the India-China border.



Source: Reproduced from Ghosh, Bandyopadhyay, and Modak (2019) with acknowledgement.

Diplomatically, India and China have signed a series of agreements on water sharing over the last 25 years. In 2002, the two countries signed a Memorandum of Understanding (MoU) on the provision of hydrological information on the Brahmaputra during the flood season, allowing China to provide water data to India to support flood forecasting during May-October each year (Indian Council of World Affairs, 2017).

In 2006 an Expert Level Mechanism (ELM) (Government of India, Ministry of External Affairs, 2006) was established as a framework to operationalise these data exchanges, coordinate flood season sharing, and discuss emergency situations. This agreement was renewed in 2008, and subsequently in 2013 and 2018. However, after 2008 India was asked to pay a fee to the Chinese for accessing data on river flow, and China in return extended the hydrological data-sharing period by two weeks, 'changing it from June 1 to October 15, to May 15 to October 15' (Barua et al., 2025). Interestingly, China does not charge a fee from Bangladesh, raising a possibility of using hydrological information selectively as leverage.

During the 73-day Doklam military standoff between India and China in mid-2017, there were reports suggesting a suspension of hydrological data sharing (Khadka, 2017) by China with India. China explained that the failure to provide data was due to upgradation and renovation (Press Trust of India, 2017) of certain stations. However, a member of Bangladesh's Joint River Commission revealed that during this period, China continued to share the figures with them (Scroll Staff, 2017), leading analysts to interpret this as a case of securitization. Hydrological data sharing resumed only after approximately a year following de-escalation in Doklam.

Once the MoUs over Brahmaputra and Satluj expired in 2023 and 2020, respectively, they have not been extended further despite repeated Indian requests. An RTI reply has revealed that "No information on hydrological data or hydro structures has been shared by China with India since 2022." (Upadhyay, 2025). The issue of transboundary rivers and sharing hydrological information was discussed at the diplomatic level, during the 23rd meeting of Special Representatives (Government of India, Ministry of External Affairs, 2024) of India and China, by NSA Ajit Doval and Foreign Minister Wang Yi, in December 2024, but it did not yield results. In January 2025, the issue was yet again raised by Foreign Secretary Vikram Misri during his visit to Beijing, where India urged China to hold an early meeting of the ELM to discuss resumption of provision of hydrological data (Government of India, Ministry of External Affairs, 2025). Interestingly, in a separate press release (Ministry of Foreign Affairs of the People's Republic of China, 2025), China maintained that the two sides will "continue cooperation on cross-border

rivers… maintain communication on the early holding of a new round of meetings of the ELM on cross-border rivers." So, while India explicitly mentioned "resumption" & "hydrological data," the Chinese side avoided such reference. Experts have suggested that such subtle differences do not inspire much confidence (Saha, 2025) and may be a sign of rupture.

3. ICIMOD: A Case of Institutional Survival

The ICIMOD is a regional intergovernmental knowledge-sharing institution headquartered in Kathmandu, Nepal. It operates as an epistemic institution focused on research and 'policy oriented work…climate advisories and the people-to-people work in supporting communities' (Acharya, 2021), concerning the Hindu Kush Himalayan (HKH) region. Significant achievements of the organization include the first comprehensive scientific assessment of the HKH region, operationalization of a cross-border flood early warning information platform, and a glacial and cryosphere monitoring network. ICIMOD's role is to generate and package science-supported results that have real impact on the lives of mountain people (Molden & Sharma, 2013). However, its normative nature has also meant that cooperation facilitated through ICIMOD remains non-binding, project-based, and contingent on continued political consent from member states.

ICIMOD faced continued challenges from COVID-19 lockdowns (ICIMOD, 2021) and political shifts in Afghanistan and Myanmar that significantly reduced work in those countries (ICIMOD, 2022). Scholarly and journalist accounts confirm that border disputes affect climate research (Bhushal, 2020) in the Himalayas. During the Galwan Valley clash, experts speculated about the future of climate cooperation, as 'Geopolitics and jingoism have been the bane of scientific collaborations' (Dreyer & Priyadarshini, 2021). Despite the tensions, in October 2020, ICIMOD successfully convened a ministerial summit of all eight members, which included participation from India and China, and there was a consensus to significantly enhance cooperation in the region (ICIMOD, 2020).

To evaluate how regional tensions affected its operating space, this section draws on a close reading of ICIMOD's annual reports from 2020 to 2023. Rather than treating them as descriptive

documents, they are analysed here as indicators of institutional stress and adaptation.

The 2020 Annual Report, which was published in 2021, makes no mention of the Galwan Valley clash or any effect of geopolitical tension on the organization. It is, instead, ambitious in its tone. It says, "The declaration includes commitments to… assess the feasibility of establishing a regional institutional mechanism." (ICIMOD, 2021, p. 7) It is imagining a future governing architecture and analogies of the Arctic, possibly alluding to the likes of the Arctic Council (ICIMOD, 2021, p. 4). Another strong emphasis has been given to science diplomacy, terming it as a "milestone in the region." (ICIMOD, 2021, p. 9) The Himalayas are framed as a shared political-ecological space, which lets us create a baseline of our understanding.

The 2021 report talks about institutional difficulties owing to COVID-19, yet reassures the stakeholders that ICIMOD was able to "fulfil its recurring institutional commitments to both an external quinquennial review (QQR) process and a five-yearly independent gender audit." (ICIMOD, 2022, p. 4). There is also an assurance made that "ICIMOD is a well-functioning organisation with core strength, coherence, and stability across its different functional areas." (ICIMOD, 2022, p. 4).

Interestingly, the 2022 report highlights strategic recalibration owing to the growing challenge of climate change. It talks about 'overhaul of its processes' to meet the agenda of 'Strategy 2030: Moving Mountains' alongside the fifth medium-term action plan (MTAP V, 2023-2026) (ICIMOD, 2023, p. 4). References made to adaptation through 'greater solidarity, accountability, and purpose than ever' (ICIMOD, 2023, p. 5) project institutional resilience. More crucially, it evolves its previous ambition by tangibly articulating an ambition to establish a 'new mechanism based on models of the Alpine and Carpathian conventions and the Arctic Council' (ICIMOD, 2023, p. 5).

The 2023 report re-emphasized the return of cooperation. The tone changes markedly: it celebrates 'ICIMOD's 40 years of working' (ICIMOD, 2024, p. 48) and re-establishes high-level advocacy, global forums, and flagship assessments. Stakeholders of ICIMOD once again endorsed it as a 'vital force in promoting regional cooperation and sustainable development' (ICIMOD, 2024, p. 49). Interestingly, in 2023, following a pause since

the COVID-19 pandemic, China too resumed funding for the organization. China's National Natural Science Foundation of China (NSFC) announced 'five key research projects were awarded funding of 2 million RMB [approximately $300,000] each for the 2024–2026 period' (International Centre for Integrated Mountain Development, nd), which bolstered regional cooperation further.

Across the 2020–2023 reports, ICIMOD does not present itself as insulated from crisis but as adapting through it. Disruptions are acknowledged, yet the institutional language consistently shifts toward restructuring and strategic renewal rather than retrenchment. By 2022, the emphasis on organisational "overhaul" and Strategy 2030 signals recalibration rather than contraction, and the 2023 report reasserts regional ambition through flagship assessments and high-level advocacy. Although this pattern hints at constraints, it also implies institutional survival under geopolitical stress.

4. Explaining Divergent Trajectories of Cooperation

If geopolitical tension were sufficient to terminate ecological cooperation, both bilateral river data-sharing and multilateral engagement through ICIMOD would have experienced similar trajectories of breakdown. Instead, the evidence reveals divergence: while hydrological data-sharing atrophied through non-renewal, ICIMOD recalibrated and endured. The difference lies not in the intensity of securitization but in institutional design, which mediates whether such pressure produces rupture or adaptation (Koremenos et al., 2001).

Both systems of cooperations operate in the same securitised India-China environment, yet their outcomes diverge. Bilateral river data sharing is organised through narrow, obligation-based memoranda that depend on periodic renewal and direct political consent. As securitisation raises the political costs (Wæver, 1995), routine cooperation renewing such arrangements becomes politically costly and administratively unattractive, making non-renewal a low-visibility way to suspend cooperation. In this context, cooperation fades through attrition rather than open termination.

By contrast, ICIMOD facilitates cooperation through multilateral and epistemic arrangements that do not require explicit bilateral

alignment. Participation is mediated through scientific programs and regional assessments. This structure allows cooperation to continue even when bilateral relations deteriorate. A relevant example of that is the ICIMOD's HKH Ministerial Mountain Summit in October 2020, where all ICIMOD members made a joint statement pushing for enhanced regional cooperation at a time of heightened tension between India and China at Galwan. The comparison suggests that securitisation does not uniformly end ecological cooperation; instead, it sorts cooperation by form. Bilateral, obligation-centered mechanisms are more vulnerable to attrition, while multilateral epistemic institutions exhibit greater resilience under prolonged geopolitical strain.

Table 1.1

	Narrow Bilateral Design	**Networked Multilateral Design**
Low Securitisation	Functional cooperation (routine data sharing pre-2017)	Functional cooperation (routine ICIMOD programming pre-2020)
High Securitisation	Attrition through non-renewal (post-Doklam, post-2020 river MoUs)	Institutional survival (ICIMOD recalibration, funding pauses, but survival)

Although ICIMOD demonstrated 'institutional survival' it however failed to achieve 'cooperative resilience' which would imply meaningful partnership as no major bilateral ecological initiatives or significant joint ventures emerged between the two countries in the post-Galwan period. Notably, following the resumption of the ICIMOD–NSFC partnership in 2023, the five publicly highlighted research projects for the 2024–2026 cycle did not include Indian partner institutions. ICIMOD therefore illustrates a case in which multilateral institutions may endure geopolitical tensions without necessarily generating meaningful bilateral cooperation among rival states.

5. Conclusion

This chapter shows that geopolitical tension does not uniformly end ecological cooperation in the Himalayas; rather, it reshapes it. Bilateral river data-sharing, dependent on renewable and

politically visible agreements, proved vulnerable to attrition under securitisation. In contrast, ICIMOD's multilateral structure enabled institutional survival despite geopolitical strain, even if meaningful India-China ecological cooperation remained limited. The divergence suggests that institutional design mediates how geopolitical pressures translate into cooperative outcomes. Ecological governance in the region is therefore not insulated from rivalry, but its durability depends on how cooperation is institutionally organised.

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13

When the River Speaks: Eco-Spiritual Imaginaries and Indigenous Ecologies in Mamang Dai's River Poems

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ABSTRACT

The poetry of Mamang Dai, one of the most celebrated voices from Arunachal Pradesh, transforms the Eastern Himalayan landscape into a living archive of memory, myth, and ecological consciousness. This paper explores how Dai's River Poems re-envision the river not merely as a geographical entity but as a sentient being, a spiritual continuum, and a repository of indigenous cosmologies. Rooted in the oral traditions of the Adi community, her poetic universe weaves together myth, ecology, and identity, challenging the anthropocentric frameworks that dominate climate discourse. By engaging closely with River Poems and other select works such as Midsummer Survival Lyrics and The Balm of Time, the paper situates Dai's poetic voice within an eco-feminist and postcolonial framework, where the river becomes a symbol of both belonging and resistance. The study highlights how Dai's intermingling of the sacred and the natural articulates an eco-spiritual ethic that resonates with the lived experiences of the North-East, a region now bearing the brunt of climate uncertainty and cultural transformation.

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Through her fusion of lyrical intimacy and mythic consciousness, Dai's poetry offers an interdisciplinary lens—bridging literature, anthropology, and environmental thought—to understand how the cultural imaginaries of the Eastern Himalayas negotiate survival, continuity and ecological wisdom in an age of change.

Keywords: *Mamang Dai, River Poems, Indigenous Ecologies, Ecofeminism, Cultural Imaginaries, Eastern Himalayas*

"The river has a soul.
In the summer it cuts through the land
like a torrent of grief.
Sometimes it is gentle,
sometimes wild."

— Mamang Dai

Introduction

The Eastern Himalayan region of Northeast India is a landscape where river, forest, and memory are inseparable. Stretching across eight states and marked by extraordinary ecological and cultural diversity, the Northeast is often described as India's biodiversity hotspot. Yet beyond ecological statistics lies a deeper truth: in this region, land is not merely territory and water is not merely a resource. Rivers determine ritual calendars, shape agricultural rhythms, inform clan genealogies, and anchor oral histories. The environment here is not an external backdrop to culture; it is constitutive of identity, spirituality, and belonging.

The region's vibrancy lies in this relational worldview. The Brahmaputra and its tributaries do not simply irrigate fields; they sustain cosmologies. Hills and forests are mapped not only geographically but also mythically. Oral traditions across indigenous communities—Adi, Apatani, Mishing, Khasi, Naga, and many others—speak of land and water as sentient presences, ancestors, and ethical witnesses. In such epistemologies, rivers remember human conduct, mountains guard secrets, and forests respond to imbalance. This worldview resists the Cartesian divide between nature and culture that underpins much modern environmental degradation.

At the same time, the Northeast today stands at a precarious ecological juncture. Intensifying floods, glacial retreat, erratic

monsoons, hydropower expansion, and extractive development projects have altered riverine systems and destabilised fragile mountain ecologies. Climate change manifests here not as abstract data but as lived vulnerability—washed-away homes, shifting riverbanks, and disrupted agrarian cycles. As environmental humanities scholars argue, such crises demand not only scientific intervention but also narrative reorientation. Literature, particularly from indigenous contexts, becomes crucial in rethinking how ecological relations are imagined and articulated.

Writers and poets from the Northeast have long engaged land as a living interlocutor. In Assam, poets such as Nilmani Phookan evoke landscape as a metaphysical presence, where riverine mist and silence carry existential weight. The poetry of Hiren Bhattacharyya similarly draws upon soil, rain, and rural memory to articulate belonging and loss. In the Khasi hills, Kynpham Sing Nongkynrih negotiates the tensions between indigenous cosmology and modernity, while Temsula Ao writes of land scarred by conflict yet sustained by ancestral memory. Across genres, from Easterine Kire to younger voices emerging from the Brahmaputra valley, the environment appears not as a picturesque setting but as an archive, witness, and ethical presence. Nature in these writings is neither pastoral escapism nor romantic excess; it is historically marked, politically charged, and spiritually resonant.

Among these voices, Mamang Dai emerges as one of the most resonant poetic chroniclers of riverine consciousness. Drawing upon the oral traditions of the Adi community in Arunachal Pradesh, her work articulates a deeply rooted eco-spiritual vision in which the river is animate, ethical, and enduring. In collections such as *River Poems, Midsummer Survival Lyrics, and The Balm of Time*, Dai transforms the river into a figure of continuity—one that carries ancestral memory while absorbing contemporary anxieties of environmental disruption.

This chapter therefore situates Mamang Dai's River Poems within the ecological and cultural textures of Northeast India, arguing that her poetic re-envisioning of the river articulates an indigenous eco-spiritual imaginary responsive to contemporary environmental precarity. Through close reading and engagement with eco-critical and postcolonial frameworks, the chapter explores how the river in Dai's poetry negotiates

memory, identity, resistance, and survival in an age increasingly marked by climate uncertainty.

2. Theoretical Framework: Ecofeminism, Postcolonial Ecology, and Environmental Humanities

The reading of Mamang Dai's *River Poems* in this chapter is grounded primarily in ecofeminist and postcolonial ecological frameworks, while remaining attentive to the broader interventions of environmental humanities. These theoretical lenses allow for an examination of how indigenous cosmologies intersect with questions of gender, land, power, and historical marginalisation. Rather than treating nature as passive landscape, both ecofeminism and postcolonial ecology foreground relationality—between human and non-human worlds, between memory and territory, and between exploitation and resistance.

Ecofeminism emerged in the late twentieth century as a critical response to the parallel structures of domination that shape both environmental degradation and gender oppression. Thinkers such as Vandana Shiva and Val Plumwood argue that patriarchal and colonial modernity constructs nature as inert, feminised matter to be controlled, extracted, and disciplined. This logic of domination not only marginalises women but also legitimises the exploitation of land and water. Within such frameworks, rivers become "resources," forests become "timber," and ecological systems are rendered economically legible but spiritually void.

Mamang Dai's poetry quietly unsettles this logic. When she asserts that "the river has a soul," she rejects the instrumental rationality that underlies extractivist development. The river in her work is neither feminised victim nor romantic mother figure; instead, it is a sentient being with agency and memory. This distinction is crucial. Dai's eco-spiritual imagination does not essentialise women as closer to nature—a tendency critiqued within strands of early ecofeminism. Rather, her work aligns more closely with postcolonial ecofeminism, which emphasises indigenous epistemologies and community-based ecological ethics without reducing them to biological determinism.

Postcolonial ecology further deepens this analysis by situating environmental crisis within histories of colonial extraction and internal marginalisation. Scholars such as Ramachandra

Guha and Rob Nixon have demonstrated how environmental degradation often unfolds as what Nixon terms "slow violence"—gradual, invisible harm disproportionately borne by peripheral regions and vulnerable communities. The Northeast of India, long subjected to political neglect and developmental intervention framed in national security or infrastructural progress, exemplifies this dynamic. Rivers are dammed in the name of energy, forests cleared for connectivity, and indigenous territories reshaped by state-driven projects.

Within this context, Dai's poetry may be read as an act of epistemic resistance. By restoring voice to the river, she re-centres indigenous ecological knowledge systems that colonial and postcolonial modernity have sought to sideline. The river becomes archive—holding ancestral memory that predates the nation-state and outlasts policy regimes. Her work thus negotiates what postcolonial theorists identify as the tension between modernity and tradition, but without romantic retreat. Instead, Dai positions myth, oral memory, and ecological consciousness as viable frameworks for confronting contemporary climate uncertainty.

Environmental humanities, as an interdisciplinary field, calls for precisely this kind of narrative intervention. Moving beyond purely scientific approaches to climate discourse, it foregrounds storytelling, ethics, and cultural memory as essential components of ecological thought. Dai's river poems participate in this reorientation. They invite readers to imagine the river not as data point or hydrological unit, but as relational presence—capable of grief, endurance, and continuity. In doing so, her poetry disrupts anthropocentric paradigms and gestures toward what might be termed a more-than-human ethics.

Through the combined lenses of ecofeminism and postcolonial ecology, therefore, this chapter reads Dai's river as a site where gendered, indigenous, and environmental concerns converge. The river's agency in her poetry is neither metaphorical excess nor mystical abstraction; it is a political and ethical claim. In an era of accelerating ecological precarity, such a claim compels a reconsideration of how literature might contribute to reimagining survival, belonging, and responsibility within the Anthropocene.

3. Close Reading and Analysis: When the River Speaks

3.1 River as speaking subject: eco-spiritual agency in River Poems

Mamang Dai's river is not a passive backdrop but a speaking presence—a more-than-human subject that holds memory, ethics, and cosmological orientation. In "Small Towns and the River," the poem begins with a human world marked by finitude—"Small towns always remind me of death"—but quickly shifts authority to the river as an enduring, sentient entity. The line "The river has a soul" is not ornamental lyricism; it is an epistemic claim rooted in indigenous relational thinking, where river, land, and ritual are co-constitutive.

The river's "speech" emerges through its knowledge and its temporality. Dai writes, "the river knows / the immortality of water." Speech here is not literal dialogue but an indigenous ecological intelligence—a way of knowing that exceeds the human. Environmental humanities scholarship often insists that ecological crisis is also a crisis of imagination and ethics; Dai's river offers precisely such a reorientation by shifting knowledge away from the human observer to the river's enduring, cyclical life.

Yet the river is not romanticised as gentle nature. It is also grief-bearing and volatile: "In the summer it cuts through the land / like a torrent of grief." The image reads powerfully in the age of climate instability—intensified floods, changing monsoons, and erratic seasonal patterns—without becoming journalistic or purely catastrophic. Dai makes the river's agency legible as affective and ethical: its "torrent of grief" is a register of disturbance in the ecological order, where the river's violence becomes a form of testimony. The poem's final movement—"we all want to walk with the gods"—ties ecology to spirituality, implying that the river's knowledge is inseparable from the community's moral universe.

In Mamang Dai's poetry, the river does not merely flow through the landscape; it speaks through memory, silence, and cyclical movement. Its speech is not articulated through human language but through ecological rhythms—flood, erosion, rain, and continuity. The river therefore functions as a narrative voice that carries ancestral knowledge and ecological warning simultaneously.

3.2 Water, feminine Interiority, and the uncertain current: "Floating Island"

If "Small Towns and the River" establishes the river's soul and knowledge, "Floating Island" intensifies Dai's eco-spiritual imagination by merging water's motion with the fragility of attachment and the uncertainty of ecological time. The landscape itself seems animate: "The sloping mountain is trying to reach me / stretching down into the water." This is not scenery; it is an agentive world reaching, desiring, responding.

The poem's centre holds a sleeping woman—"Deep in my centre a woman is asleep… / vivid with dreams"—while "the birds of summer are nesting in her breast." Here, Dai threads ecofeminist resonances without collapsing into simplistic "woman = nature" essentialism. The woman's body becomes a site of seasonal continuity and vulnerability, while the "spinning current" signals unpredictability: "Who knows which way the spinning current will spin." Read through postcolonial ecofeminism, this uncertainty can be aligned with how indigenous ecologies are increasingly destabilised by development regimes and climate change—forces that alter the "current" of life in ways communities cannot fully control.

The closing line—"my heart clings to the life of water"—turns water into an ethical anchor. Dai's river is not merely ecological; it is spiritual and affective, sustaining a mode of belonging that is simultaneously personal and collective. This is exactly the interdisciplinary strength your title promises: the poem speaks ecologically, spiritually, emotionally, and politically all at once.

3.3 Indigenous memory as ecological archive: "An Obscure Place" and the place of stories

Dai's insistence that community history is carried not only in documents but in landscape, oral memory, and stories is noteworthy. A frequently cited opening from "An Obscure Place" states: "The history of our race begins with the place of stories… Nothing is certain. / There are mountains. Oh! There are mountains." This is indigenous epistemology written as poetics: "place" is archive; stories are a mode of ecological record-keeping; mountains are not inert geography but storied presences.

This matters for environmental humanities because it refuses the division between cultural memory and ecological knowledge.

When ecological change occurs—deforestation, dam-building, militarised governance, extractive development—the damage is not only environmental but epistemic: it disrupts the "place of stories." That is why Dai's poems keep returning to hills, rivers, clouds, and forests as living witnesses. The river "speaks," in this framework, because landscape itself is a mnemonic and moral system.

3.4 Kinship ecologies and more-than-human ethics: Midsummer Survival Lyrics

Even when we cannot access the full collection text freely online, scholarship quoting Dai shows how Midsummer Survival Lyrics explicitly builds a kinship-based ecological ethic. One cited excerpt from her poem "Birthplace" reads: "We are the children of the rain / of the cloud woman, / brother to the stone and bat." This is a compact articulation of indigenous ecology: humans are not masters of nature but relatives within a shared web of life.

From an interdisciplinary lens, this does three things at once:it echoes relational cosmologies where rain/cloud/animals are kin rather than resources. it breaks anthropocentrism by placing stone and bat within the circle of belonging.: if humans are "children of the rain," then altered rainfall patterns and destabilised seasons are not just "weather"—they are disruptions of kinship, identity, and survival.

3.5 Rivers as power, warning, and climate precarity

Dai's river is also a force that warns and reverses human arrogance. Discussing her poem "Rivers" notes her emphasis on the river's sublime power, including its capacity to "capsize" what humans build or assume stable. Even in a single word, the logic is clear: the river is not scenery; it is an agent capable of undoing human certainties.

Read through environmental humanities, this becomes a critique of modernity's infrastructural confidence (dams, embankments, "control" of water). Read through postcolonial ecology, it becomes a critique of development that treats frontier ecologies as exploitable. Read through eco-spiritual imagination, it becomes a reminder that rivers are not only hydrological systems but moral presences.

A significant dimension of Mamang Dai's poetry lies in its articulation of indigenous ecological consciousness, where land,

water, and human communities exist within an interconnected web of relationships. In many indigenous traditions of Northeast India, particularly among the Adi community to which Dai belongs, nature is not conceived as a passive landscape but as a living, sentient presence that shapes cultural identity and ethical conduct. Rivers, mountains, forests, and rain are understood not merely as natural resources but as participants in the moral and spiritual life of the community. Dai's poetry reflects this worldview by repeatedly presenting the river as a speaking subject, a witness to history, and a carrier of ancestral memory.

In poems such as *Small Towns and the River*, the river is portrayed as possessing knowledge that transcends human temporality. When Dai writes that "the river has a soul" and that "the river knows the immortality of water," she foregrounds a cosmological perspective in which water embodies continuity and cyclical regeneration. Such imagery aligns with indigenous ecological philosophies that recognise the agency of natural elements and emphasise reciprocity between humans and their environment. The river's voice in Dai's poetry thus becomes a medium through which ecological knowledge is transmitted—knowledge rooted in observation, ritual practice, and generational memory rather than purely scientific abstraction.

At the same time, Dai's poetic landscape subtly registers the disruptions caused by environmental change. The river in her poems is not always tranquil or harmonious; it is capable of turbulence and grief. The line describing the river cutting "through the land like a torrent of grief" suggests a profound ecological disturbance. While the poem does not explicitly name climate change or environmental destruction, the imagery evokes the increasing unpredictability of river systems in the Eastern Himalayan region. Floods, erosion, and shifting river courses have become recurring realities across the Brahmaputra valley and surrounding areas. By portraying the river as emotionally and spiritually affected, Dai transforms environmental instability into a moral narrative in which ecological imbalance reflects a deeper rupture in human relationships with the land.

Ultimately, Mamang Dai's poems present the river as both witness and teacher in an era of ecological uncertainty. Through the voice of the river, her work reveals how indigenous cosmologies continue to offer meaningful frameworks for understanding environmental change. The river's speech,

therefore, is not merely poetic expression; it is a call to recognise the fragile interdependence of human and non-human worlds in the Anthropocene.

4. Rivers as Ecological and Cultural Symbols: Northeast Indian Literature and World Literature

The symbolic presence of rivers in literature is neither geographically confined nor culturally isolated. Across world literatures, rivers have long served as powerful metaphors for life, time, transformation, and continuity. However, the representation of rivers in the literature of Northeast India—particularly in the poetry of Mamang Dai—offers a distinctive ecological and cultural perspective that differs in significant ways from many canonical representations of rivers in global literary traditions.

In Northeast Indian literature, the river is frequently portrayed as a living entity embedded within indigenous cosmology. Writers from the region often draw upon oral traditions and community-based ecological knowledge, where rivers are regarded as ancestors, guardians, and moral witnesses. Mamang Dai's poetry exemplifies this worldview. In poems such as *Small Towns and the River*, the river is endowed with consciousness and memory—"the river has a soul" and "the river knows the immortality of water." Such lines reflect an indigenous ecological philosophy in which natural elements possess agency and participate actively in the cultural life of the community. The river is not merely symbolic; it is relational, forming part of a network of kinship that includes land, animals, and human beings.

This perspective contrasts with many representations of rivers in Western literary traditions, where rivers often function primarily as metaphorical or narrative devices rather than spiritual presences. For instance, in works such as *Heart of Darkness*, the Congo River operates as a symbolic pathway into the psychological and moral darkness of colonial enterprise. The river here is not a living agent but a narrative conduit through which imperial power and existential anxiety unfold. Similarly, in *Adventures of Huckleberry Finn*, the Mississippi River represents freedom and escape from the constraints of society. While the river shapes the protagonists' journey, it largely remains a

symbolic landscape rather than an animate entity possessing its own voice.

The difference becomes clearer when one considers the role of indigenous epistemologies. In Mamang Dai's poetry, the river is inseparable from oral traditions, myths, and communal memory. It functions as a cultural archive that remembers histories preceding colonial and modern state structures. This approach aligns with indigenous ecological philosophies found in many parts of the world, where land and water are viewed as animate relatives rather than inert resources. However, Dai's work remains unique in the way it integrates this worldview within contemporary English-language poetry, creating a hybrid literary space where indigenous cosmology intersects with modern environmental discourse.

At the same time, important similarities can also be observed between Northeast Indian literature and certain strands of world literature that foreground ecological consciousness. Writers such as Gary Snyder and Wendell Berry similarly emphasise the ethical relationship between humans and landscape. Like Dai, these writers challenge anthropocentric views of nature and advocate a deeper sense of ecological belonging. However, while Snyder and Berry draw upon Zen philosophy or agrarian traditions, Dai's ecological imagination emerges from the indigenous cosmologies of the Eastern Himalayas.

Thus, the river as a literary symbol performs both universal and culturally specific functions. Across world literature, rivers often signify movement, transformation, and the passage of time. In Northeast Indian literature, however, the river extends beyond metaphor to become a speaking ecological presence—a guardian of cultural memory and a witness to environmental change. Mamang Dai's poetry exemplifies this distinctive vision by presenting the river as a sentient entity capable of grief, endurance, and wisdom. Through this perspective, her work contributes to global environmental literature while simultaneously preserving the unique ecological and spiritual sensibilities of the Northeast.

5. Conclusion

Mamang Dai's poetry invites readers to reconsider the ways in which rivers, landscapes, and communities are intertwined

within the ecological imagination of the Eastern Himalayas. Through the poems discussed in this chapter, it becomes evident that Dai's river is far more than a geographical feature or literary metaphor. It is a living archive that carries memory, grief, spirituality, and continuity. The river speaks through silence, through seasonal rhythms, and through the stories embedded in land and water. By attributing voice and agency to the river, Dai challenges the anthropocentric frameworks that have historically shaped modern attitudes toward nature.

The eco-spiritual imagination that emerges from Dai's poetry is deeply rooted in indigenous ecological knowledge. In the cosmology of the communities of Northeast India, rivers are not inert resources but relational presences that sustain cultural life. At the same time, Dai's work resonates strongly with contemporary discussions in environmental humanities and climate discourse. The instability and turbulence of rivers that appear in her poems echo the realities of a world increasingly shaped by environmental disruption. Floods, erosion, and shifting river currents are not merely natural phenomena but manifestations of deeper ecological imbalance.

What makes Mamang Dai's poetry particularly significant is its ability to bridge multiple disciplines and perspectives. Her work operates simultaneously as literature, cultural memory, ecological reflection, and philosophical inquiry. By weaving together indigenous cosmology, lyrical imagination, and environmental awareness, Dai creates a poetic space where rivers become teachers and storytellers. Through this interdisciplinary lens, her poetry reminds readers that ecological survival depends not only on technological solutions but also on the restoration of ethical relationships between humans and the more-than-human world.

In this sense, the river in Dai's poetry ultimately emerges as both witness and guide in the Anthropocene. It records histories of belonging while simultaneously warning of ecological fragility. To listen to the river, as Dai's poetry encourages us to do, is to recognise the deep interconnectedness that sustains life in the Eastern Himalayan landscape and beyond.

The enduring wisdom of this vision is perhaps best captured in Mamang Dai's own words:

"The river has a soul.
The river knows
the immortality of water."

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14

Reclaiming the Lost Symbiosis: Identity, Ecology, and Traditional Knowledge in *When the River Sleeps* and *The Living Mountain*

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ABSTRACT

This paper undertakes a comparative ecocritical reading of Easterine Kire's When the River Sleeps (2014) and Amitav Ghosh's The Living Mountain (2022) to examine how contemporary Indian writing negotiates questions of identity, belonging, and ethics through ecological consciousness. These two texts are brought together because they emerge from distinct yet convergent traditions: Kire writes from within Naga indigenous cosmology, while Ghosh addresses a global readership through a parabolic critique of modernity. Drawing on ecocriticism, ecofeminism, and post- humanist theory, the paper analyses narrative voice, myth, symbolism, and animistic imagination to show how both authors challenge anthropocentric epistemologies. Kire's novel imagines a sentient landscape where rivers dream, and spirits guide human action, while Ghosh's prose meditation exposes the epistemic violence of modern rationality that reduces sacred mountains to inert resources. By foregrounding indigenous and relational ways of knowing, the texts suggest that contemporary identity crises are inseparable from ecological alienation.

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The paper argues that both works envision belonging not as mastery over nature but as ethical participation in a living, interdependent world.

Keywords: *Ecocriticism, Indigenous Knowledge, Posthumanism, Identity, Environmental Ethics*

1. Introduction

The escalating ecological crises of the contemporary world have compelled literary studies to rethink long-standing assumptions about the relationship between humans and the nonhuman world. Ecocriticism, as Cheryll Glotfelty famously argues, urges critics to read literature as part of "the global environmental crisis," thereby dismantling the illusion of textual autonomy and foregrounding literature's ethical and material entanglements with the natural world (Glotfelty and Fromm 1996: xviii). Within this critical turn, questions of identity, belonging, and subjectivity are increasingly understood as ecological rather than purely cultural or psychological concerns. Ecocriticism reorients literary studies toward the ethical and material entanglements between humans and the nonhuman world.

Indian writing in English, shaped by the intersecting legacies of colonial exploitation, indigenous cosmologies, and uneven trajectories of modernisation, offers a particularly fertile ground for examining these entanglements. Colonial epistemologies systematically desacralized land, transforming living landscapes into resources and territories, while many indigenous traditions across the subcontinent continued to imagine nature as animate, sentient, and morally responsive. Contemporary Indian writers often negotiate this tension by juxtaposing modern rationality with older, relational ways of knowing, revealing how ecological violence is inseparable from cultural erasure and identity loss (Guha 2000; Huggan and Tiffin 2010).

Easterine Kire's *When the River Sleeps* and Amitav Ghosh's *The Living Mountain* respond to this ecological moment by recovering traditional knowledge systems that view nature as alive, relational, and ethically charged. Although formally distinct, Kire's text is a novel deeply rooted in Naga oral traditions and animistic cosmology, while Ghosh's work takes the shape of a

brief parable addressed to a planetary readership; both texts interrogate the violence of modern anthropocentrism. They expose how modernity's insistence on mastery, extraction, and rational control fractures the human relationship with the natural world, producing not only environmental degradation but also a profound crisis of meaning and belonging.

By placing these two texts in conversation, this paper argues that Kire and Ghosh reimagine identity through ecological embeddedness, dissolving the rigid separation between nature and culture that underpins modern thought. In their works, belonging emerges not as ownership over land but as ethical participation within a living, interdependent world. Rivers that sleep and mountains that live are not merely metaphors but narrative strategies that challenge dominant epistemologies, urging readers to reconsider what it means to be human in an age of ecological precarity.

This paper examines how contemporary Indian writing in English reconfigures identity and belonging through ecological consciousness and traditional knowledge systems. It asks how literary representations of animate landscapes, indigenous cosmologies, and sacred geographies challenge anthropocentric and modernist epistemologies that separate nature from culture. Through a comparative textual analysis of Easterine Kire's *When the River Sleeps* and Amitav Ghosh's *The Living Mountain*, the study employs ecocritical, ecofeminist, and posthumanist frameworks to analyse narrative voice, symbolism, myth, and allegorical form. By reading these texts alongside the ecological and cultural contexts of the Northeast and the Himalayan region, the paper foregrounds place-based epistemologies and relational modes of being. Methodologically, the paper combines close reading with contextual and theoretical analysis to demonstrate how literary texts function as ethical interventions, offering alternative imaginaries of identity grounded in interdependence, care, and ecological responsibility. The selection of Easterine Kire and Amitav Ghosh is informed by their distinct yet complementary engagements with ecological crisis, Indigenous epistemologies, and the politics of belonging in contemporary Indian writing in English. While Kire writes from within the lived cultural and ecological realities of Northeast India, Ghosh addresses environmental collapse through a broader planetary and civilizational framework. Reading these texts together enables

a comparative exploration of how local Indigenous cosmologies and global ecological anxieties intersect in literary representations of identity and environmental ethics. Methodologically, this paper adopts a reflexive position attentive to the cultural and ecological specificities of the Indian context, particularly the continuing marginalisation of Indigenous knowledge systems within dominant developmental discourses. Rather than treating these epistemologies as symbolic or nostalgic, the study approaches them as living ethical frameworks that offer critical alternatives to extractivist modernity.

2. Theoretical Framework: Ecocriticism, Ecofeminism, and Posthumanism

Ecocriticism provides the primary theoretical lens for this study, particularly through its sustained effort to decentre the human subject and challenge anthropocentric modes of reading. As Lawrence Buell argues, environmentally oriented texts unsettle "the conventional hierarchy that places human concerns above all others," compelling readers to recognise the agency and ethical significance of the nonhuman world (Buell 1995: 7). Such a perspective reconfigures literature as a space in which human narratives are inseparable from ecological contexts, and in which nature emerges not as a silent backdrop but as an active participant in meaning-making.

Posthumanist theory extends this critical intervention by interrogating the very foundations of humanism that have historically privileged human rationality, autonomy, and mastery. Rosi Braidotti conceptualises posthumanism as an ethical and philosophical orientation that understands humans as "embedded in a web of relations with non-human agents," thereby dissolving rigid boundaries between the human and the nonhuman (Braidotti 2013: 49). This framework enables a reading of literary texts that foregrounds interdependence, vulnerability, and relational existence rather than domination and control.

Ecofeminism adds a crucial intersectional dimension to this analysis by linking environmental exploitation to the marginalisation of women and indigenous communities. Vandana Shiva observes that dominant models of development are structured around "the subjugation of both nature and

women," a logic rooted in colonial and patriarchal epistemologies (Shiva 1988: 38–39). In contrast, indigenous knowledge systems often resist such binaries by emphasising care, reciprocity, and ethical coexistence with the natural world. By bringing ecocriticism, posthumanism, and ecofeminism into dialogue, this paper reads Easterine Kire and Amitav Ghosh as writers who articulate alternative modes of being, modes that envision identity not as human exceptionalism but as relational belonging within a shared ecological continuum.

3. Identity, Ecology, and Traditional Knowledge in the Indian Context

In the Indian context, questions of identity are deeply entangled with ecology, geography, and inherited systems of knowledge. Unlike modern Western conceptions of identity as individual, autonomous, and abstracted from place, many Indian and indigenous worldviews imagine identity as relational, formed through sustained engagement with land, climate, rivers, forests, and mountains (Gadgil, Berkes, and Folke 1993). Traditional knowledge systems across the subcontinent have long recognised nature not as an external object to be controlled, but as a living presence that shapes cultural memory, ethical conduct, and collective belonging

This relational understanding of identity is particularly pronounced in the northeastern region of India, a space marked by dense forests, riverine landscapes, and fragile mountain ecosystems. Historically marginalised within dominant national narratives, the Northeast has preserved diverse indigenous epistemologies that resist homogenising models of development. Communities in this region often conceive of land not as private property but as communal, sacred, and animated. Rivers, hills, and forests are bound to ancestral memory and spiritual belief, shaping modes of life rooted in reciprocity and restraint (Baruah 2005). The ecological knowledge embedded in these practices stands in stark contrast to extractivist frameworks imposed through colonial administration and later intensified by postcolonial developmental agendas.

The Himalayas have long been imagined as sacred ecological entities rather than inert geographical formations. More than a geographical formation, the Himalayas have traditionally been revered as the

living entities' abodes of gods, sources of rivers, and guardians of climatic balance. Sacred rivers such as the Ganga, Yamuna, and Brahmaputra originate in these mountains, reinforcing the perception of the Himalayas as life-giving rather than inert. For communities living in and around the Himalayan region, mountains are not resources to be mined but presences that command reverence, care, and ethical responsibility (Bernbaum 1997). This worldview, however, has increasingly come under threat from infrastructural expansion, tourism, militarisation, and climate-induced fragility.

The erosion of traditional ecological knowledge in both the Northeast and the Himalayan belt has profound implications for identity. As development discourses prioritise economic growth over ecological balance, indigenous relationships with land are delegitimised, and ways of knowing rooted in myth and spirituality are dismissed as irrational or obsolete. This process produces not only environmental degradation but also cultural dislocation, where communities are alienated from the landscapes that once anchored their sense of self and belonging. Identity, in such contexts, becomes fractured, caught between inherited relational epistemologies and imposed modern rationalities.

It is within this contested terrain that the works of Easterine Kire and Amitav Ghosh gain particular significance. By foregrounding indigenous cosmologies and sacred landscapes, both writers intervene in dominant narratives of progress and development. Their texts recover traditional knowledge systems not as nostalgic remnants of the past but as viable ethical frameworks capable of responding to contemporary ecological crises. Ghosh underscores a troubling transformation: once the Anthropoi introduce extractive practices to Mahaparbat, the ideology of exploitation gradually permeates the Varavoi community itself, so that the younger generation comes to desire inclusion within the same destructive economic order that threatens their sacred landscape. In doing so, they reaffirm the importance of place-based identities in the Indian context and demonstrate how ecological consciousness is central to any meaningful reimagining of belonging in a rapidly changing world.

4. Animistic Landscapes and Indigenous Epistemology in *When the River Sleeps*

When the River Sleeps is deeply embedded in Naga cosmology, a worldview in which rivers, forests, stones, and spirits are not peripheral to human existence but integral to everyday life and ethical orientation. The novel follows Vilie, a hunter who undertakes a perilous journey to obtain a stone from a sleeping river, a quest that is simultaneously spiritual, ecological, and epistemological. As Kire writes, "The river was alive, listening, waiting, as it always had," a statement that collapses the distinction between human sentience and nonhuman presence (Kire 2014: 62).

Narrative voice plays a crucial role in normalising this animistic worldview. Rather than explaining or rationalising the presence of spirits, the narrative assumes their reality as a matter of fact. This narrative strategy resists the epistemic violence of colonial discourse, which historically dismissed indigenous cosmologies as myth or fantasy. Symbolism further reinforces this perspective: the forest in Kire's novel is not a neutral landscape or extractable resource but a morally charged space in which human actions invite consequences. Vilie's survival depends not on domination or conquest but on restraint, attentiveness, and respect for nonhuman entities, foregrounding an ethics of coexistence rooted in reciprocity.

Scholars of Indigenous ecocriticism have increasingly argued that animistic narration functions not merely as a stylistic device but as an epistemological intervention that destabilises Western rationality. Graham Huggan and Helen Tiffin observe that postcolonial ecological narratives often resist colonial frameworks by foregrounding Indigenous cosmologies in which the nonhuman world possesses agency and moral significance. Similarly, Serenella Iovino's concept of 'storied matter' suggests that landscapes themselves carry memory, ethics, and narrative presence, allowing literature to reimagine ecological environments as active participants rather than passive settings. Kire's novel participates in this tradition by treating rivers, forests, and spirits as narrative presences that shape human conduct and ethical responsibility.

Through its myth-inflected narrative structure, *When the River Sleeps* actively resists the colonial and modern erasure of indigenous epistemologies. Identity, within this framework, is not an autonomous or individual possession but a relational condition sustained through ethical engagement with land, spirits, and nonhuman life. The novel thus enacts what ecofeminist critics identify as an ethics of care, one grounded in humility, interdependence, and sustained attentiveness to the more-than-human world, offering an alternative model of belonging that challenges anthropocentric and extractivist modes of being (Plumwood 2002).

5. Modernity, Loss, and Ethical Warning in *The Living Mountain*

Amitav Ghosh's *The Living Mountain* adopts a markedly different literary form from Kire's novel, yet it ultimately arrives at a closely aligned ethical position. Written as a brief parable addressed to future generations, the text mourns the destruction of a once-sacred mountain under the pressures of modern developmental logic. Ghosh explicitly critiques the epistemological framework that reduces mountains to "mere heaps of rock," exposing the violence inherent in viewing the natural world as inert matter available for extraction. In doing so, the parable confronts the instrumental rationality of modernity that severs ecological entities from their cultural, spiritual, and ethical significance (Ghosh 2022: 9).

Unlike the immersive, myth-inflected narrative of *When the River Sleeps*, Ghosh employs direct address, allegory, and temporal distance to heighten the urgency of ecological loss. The parable's voice speaks from a future shaped by irreversible damage, transforming the mountain into a silent witness whose presence is felt most powerfully through its absence. The parable mourns ecological destruction through absence and lament, exposing what Ghosh elsewhere calls the

"great derangement" of modern thought. This loss resonates with Ghosh's broader critique of modernity's "failure of imagination," which refuses to acknowledge nonhuman agency (Ghosh 2016).

Recent scholarship on Amitav Ghosh has similarly interpreted The Living Mountain as a critique of neoliberal development and ecological extractivism. Kumar and Sharma argue that

the text exposes the interconnected operations of empire and capitalism through the destruction of sacred ecological spaces, demonstrating how modernity transforms living landscapes into economic commodities. Their reading aligns with Rob Nixon's concept of 'slow violence,' where environmental destruction unfolds gradually yet irreversibly, often remaining invisible within dominant narratives of progress. Ghosh's parable captures this slow violence through mourning and absence rather than spectacle, emphasising the long-term ethical consequences of ecological exploitation.

The loss articulated in *The Living Mountain* is therefore not only environmental but also cultural and spiritual. With the mountain's destruction, an entire mode of relating to the world disappears, one grounded in reverence, restraint, and interdependence. Ghosh suggests that modernity's epistemic violence lies not merely in physical devastation but in its capacity to erase alternative ways of knowing and inhabiting the Earth. Sacred landscapes, once understood as living presences that demanded ethical engagement, are rendered voiceless within the discourse of progress.

Ghosh's critique resonates strongly with posthumanist concerns by exposing the limits and dangers of human exceptionalism. The parable implies that modern identity constructed around extraction, mastery, and technological confidence is fundamentally unsustainable because it depends on the denial of nonhuman agency. In reducing the mountain to a resource, humanity not only destroys the ecological world but also impoverishes its own ethical imagination. *The Living Mountain* thus functions as a moral warning, urging readers to recognise that the survival of human communities is inseparable from the continued vitality of the more-than-human world.

6. Comparative Discussion: Identity, Belonging, and the More-than-Human

Read together, *When the River Sleeps* and *The Living Mountain* generate a productive comparative field in which differing narrative forms, epistemologies, and scales of address converge around a shared ecological ethic. Easterine Kire's novel looks inward, grounding its vision of belonging in indigenous myth, oral memory, and lived cosmology specific to the Naga

landscape. Amitav Ghosh's parable, by contrast, looks outward, addressing a global and intergenerational readership through allegory and warning. Yet this difference in orientation does not signal divergence; rather, it reveals how ecological consciousness operates across both local and planetary registers. Both texts unsettle the anthropocentric assumption that humans stand apart from the natural world, exposing instead a relational ontology in which human existence is inseparable from nonhuman life.

These concerns resonate strongly with recent environmental debates surrounding Indigenous ecological stewardship and climate justice. Contemporary environmental humanities scholars increasingly argue that Indigenous knowledge systems offer crucial alternatives to extractivist models of development, particularly in regions facing ecological precarity. The growing recognition of legal personhood granted to rivers and mountains in countries such as New Zealand, Ecuador, and India reflects an emerging global shift toward relational ecological ethics that challenge anthropocentric legal and philosophical frameworks. Read in this context, Kire and Ghosh anticipate broader debates about nonhuman agency, ecological rights, and the ethical necessity of rethinking human exceptionalism in the Anthropocene.

The contrast between the two works is particularly evident in their narrative strategies. Kire embeds ecological ethics within an immersive narrative where rivers, forests, and spirits are experienced as everyday presences. The animistic worldview is normalised through narrative voice, making relational coexistence appear neither symbolic nor exceptional but ethically necessary. Ghosh, on the other hand, employs distance, direct address, and temporal displacement to dramatise ecological loss.

Belonging in both texts is defined not through ownership, development, or human dominance, but through participation and attentiveness. In *When the River Sleeps*, belonging emerges through listening to rivers that sleep, forests that judge, and spirits that demand ethical restraint. Vilie's survival depends on his ability to recognise nonhuman agency and respond with humility. In *The Living Mountain*, the failure to listen becomes central: the mountain is silenced, reduced to a resource, and ultimately erased. Ghosh thus frames ecological destruction

as an epistemic failure, where the refusal to acknowledge nonhuman life as meaningful leads to irreversible loss.

By foregrounding indigenous knowledge systems and relational ethics, both texts reimagine identity as ecological belonging, insisting that ethical life emerges only through sustained engagement with the more-than-human world.

7. Conclusion

This paper has argued that Easterine Kire and Amitav Ghosh reimagine identity and belonging through ecological consciousness and the recovery of traditional knowledge systems that resist the epistemic violence of modernity. Through a comparative reading of *When the River Sleeps* and *The Living Mountain*, the study has shown how both texts challenge anthropocentric and modernist worldviews that reduce nature to inert matter and position the human as autonomous, exceptional, and dominant. Instead, Kire and Ghosh foreground relational modes of being that recognise the agency, sentience, and ethical presence of the nonhuman world.

By situating identity within ecological embeddedness, these texts expose the profound costs of severing human life from indigenous and relational ways of knowing. Kire's animistic narrative, grounded in Naga cosmology, presents coexistence, attentiveness, and restraint as conditions of survival. At the same time, Ghosh's parable stages the consequences of ecological and epistemic deafness through loss, absence, and mourning. Together, they demonstrate that environmental degradation is inseparable from a crisis of meaning, belonging, and ethical responsibility. The destruction of rivers and mountains mirrors the erosion of alternative epistemologies that once sustained reciprocal relationships between humans and the more-than-human world.

Read through the lenses of ecocriticism, ecofeminism, and posthumanism, these works ultimately call for a reorientation of human self-understanding. They urge a shift away from extractivist and mastery-driven identities toward modes of existence grounded in care, humility, and interdependence. In an era marked by ecological precarity and climate catastrophe, such literary interventions are not merely aesthetic reflections but ethical provocations. By recovering indigenous cosmologies

and relational ethics, *When the River Sleeps* and *The Living Mountain* compel readers to reconsider what it means to live responsibly on a shared planet, where belonging is not a matter of possession, but of participation within a living, interconnected world.

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15

Narrating Change: Exploring Intersections of Culture, Literature, and Climate in the Eastern Himalayas

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ABSTRACT

Northeast India, while being celebrated as a global biodiversity hotspot, often finds itself at the crossroads with severe climate-induced vulnerability. However, the academic discourse around this region has primarily focused on scientific studies, policy analysis, and the immediate social impact of these issues. Arguably, a thorough understanding of climate change in this vibrant yet complex, multiethnic region is incomplete without considering the cultural and literary imaginaries of its people. To explore this under-researched convergence of climate change, literary expression and cultural imaginaries, this chapter adopts a critical understanding approach. The study will delve into local folklore, oral traditions, and sacred narratives. Contemporary regional literature from Northeast India presents itself as powerful cultural archives that both reflect and mediate the experience of detrimental climate change in the Eastern Himalayas.

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It seeks to highlight how the cultural and literary imaginaries of Northeast India provide an essential, humanistic approach to support climate science and policies for the region and its people. It will also analyse the reiterating tragedies such as ecological loss, hydro-anxiety with respect to incessant floods and withering springs in the region, and cultural resilience in these narratives. Most importantly, the chapter will investigate the role of literary and cultural outlooks in shaping local and indigenous-led adaptation strategies and environmental consciousness. The chapter seeks to fill up a significant research gap by centering itself on the cultural and local narratives as it offers a more delicate, humanistic and mindful understanding of climate change in the Eastern Himalayas.

Keywords: *Climate Change, Cultural Imaginaries, Narratives, Northeast India*

1. Introduction

The Eastern Himalayas, particularly Northeast India, are an ecological paradox of being a biodiversity hotspot that is simultaneously highly vulnerable to climate change. This vulnerability is clearly visible in the region's riverine ecology that fundamentally defies fixed cartographic boundaries. As environmental historian Arupjyoti Saikia (2019) documents, Assam's floodplains reject the rigid binaries of solid earth and flowing water. Historically, the people of this region adapted to the terrain by recognizing that the shifting courses of the river made land and water inseparable. Consequently, the making and unmaking of these floodplains is a continuous process of hydrological volatility that is now being severely accelerated by climate change.

Despite the region facing active and volatile challenges, state policies and mainstream literature often fail to capture the crisis. Amitav Ghosh (2016) diagnoses the root of this failure as a crisis of culture and imagination in grasping the urgency of climate change and its effects. The mainstream discourse tends to objectify nature as a passive backdrop, refusing to acknowledge the dynamic, almost sentient agency of the landscape. Ghosh terms this modern disconnection with ecological reality as "The Great Derangement" (2016, p. 11), a mindset that actively

prevents communities from recognizing and properly adapting to the realities of their changing environment.

To address this escalating crisis, this chapter posits that effective mitigation requires bridging empirical science with lived experience through the region's rich cultural archives. By critically examining indigenous folklore and literary imaginaries, this study proposes these archives act as vital, pragmatic accounts of adaptation. Thus, integrating this humanistic vision with scientific frameworks is essential to develop robust strategies that recognize the agency of both the landscape and its people.

2. The Anatomy of Hydro-Anxiety

To understand climate change in the Eastern Himalayas, there is a need to look beyond the data and listen to the people. This section introduces the idea of hydro-anxiety, an emerging term for the psychological pain and existential insecurity that comes from extreme water insecurity. Here, hydro-anxiety is a collective trauma marked by a swinging pendulum between two extremes; devastating floods in the valleys and the quiet crisis of springs going dry in the hills. However, conventional administrative frameworks often fall short in capturing the full scope of this distress. They reduce this trauma to physical displacement, ignoring the subjective factors at play. Regional literature offers a better approach to represent these complexities. It describes this anxiety as a deep ontological and spiritual dislocation, rooted in an environment that actively shapes human life.

2.1 Trauma, Erosion and Riverine Agency

The first dimension of hydro-anxiety comes from the overwhelming scale of flooding across river plains. The main trauma goes beyond temporary water damage. Aggressive riverbank erosion systematically eats away at the land. When a river takes a village, it destroys farming livelihoods and breaks the deep sense of security that a home provides. Communities get trapped in endless cycles of displacement. Regional writers have captured this vulnerability by showing the environment as a powerful, active force rather than just scenery.

Amitav Ghosh articulates this paradigm shift in his analysis of the volatile riverine geographies of the East, asserting that "the land here is demonstrably alive; that it does not exist solely, or even incidentally, as a stage for the enactment of human

history; that it is [itself] a protagonist" (Ghosh, 2016, p. 10). In Ghosh's perspective, agency is located not solely on the human but as something distributed across the landscape. This riverine agency is vividly embodied in Easterine Kire's novel *When the River Sleeps* (2014), which portrays the watercourse not as an inert natural resource but as a sentient, formidable entity. Kire describes the sudden, violent awakening of the water, noting that "the river had come alive!" (Kire, 2014, p. 11). As the river assaults the protagonist, it is depicted as being "almost human as it pushed him down and under... as though it would strangle him" (Kire, 2014, p. 105). Within this narrative framework, the river operates as a volatile character deeply entwined with the communities' existence. Recognizing this uncanny intimacy with the nonhuman world is essential to comprehending the profound psychological toll inflicted by the region's climate crisis.

2.2 Sacred Geography and Solastalgia

Valley regions face catastrophic flooding, while in the hills a different crisis unfolds as mountain springs are drying up. For the people living there, these water sources have significant spiritual importance. For them, this drying up points to a loss that surpasses the failure of governance there or even the resources being scarce.

Mamang Dai articulates this phenomenon through the idea of a sacred geography in works such as *The Legends of Pensam* (2006). In this collection of stories as well as in her poetry, Dai illustrates how the mountains function as living, breathing archives of community memory. Her poem "The Voice of the Mountain" personifies the landscape as an eternal witness: "I am an old man sipping the breeze that is forever young/ In my life I have lived many lives/My voice is sea waves and mountain peaks." (Dai, 2005, lines 14-16) The terrain itself acts as a repository for "the past that recreates itself" (Dai, 2005, line 21). When a spring withers or a hillside is irrevocably altered, the narratives deeply embedded within that specific topography are erased. This destruction is not exclusively environmental; it constitutes the erasure of a sacred identity, closely mirroring the psychological condition of solastalgia. Solastalgia runs parallel to environmental change, referring to "the pain or distress caused by the loss of, or inability to derive solace connected

to the negatively perceived state of one's home environment" (Albrecht et al., 2007, p. 96). The speaker in Dai's poem captures this climate-induced distress- "I know, I know these things/ as rocks know" (2005, lines 24-25). When the rocks are silenced by ecological degradation, an entire epistemological framework of indigenous systems disappear. Ultimately, the literary contributions of writers like Kire and Dai demonstrate that within the Eastern Himalayas, hydro-anxiety goes beyond the fear of extreme weather and becomes a persistent grief that mourns the destabilization of a sacred geography. Climate policies must, therefore, address not only the physical loss of territory but also the severe cultural rupture that accompanies this psychological reality.

3. Failure of the "Concrete" Approach

The psychological weight of hydro-anxiety demands attention. But it is equally important to examine how governments have responded to this crisis. For most of the decades since independence, the focus in the Eastern Himalayas has always been relying heavily on engineering through mega-dams, concrete embankments, or similar hard infrastructure. This perspective involves a technocratic gaze rooted in the belief that technical solutions can solve environmental problems. This approach has deeper roots. As Amitav Ghosh (2016) has argued, modern society suffers from a failure of imagination that treats nature as passive and predictable rather than dynamic and powerful. This worldview fundamentally denies the landscape any real agency. The drive to construct rigid barriers across ever-changing terrain stems from a desire to demonstrate technological control over nature, treating rivers as fixed entities to be subdued rather than living systems with agency.

In Northeast India, this engineering mindset passed directly into post-colonial governance. The catastrophic 1950 earthquake radically reshaped the region's terrain, triggering massive hydrological instability. The devastating floods of 1951, as environmental historian Arupjyoti Saikia (2019) documents, became the decisive impetus for the valley's massive embankment program. The appeal of embankments was simple: they promised quick, localized protection for farming communities. Saikia points out that, initially, "the monsoon crop was saved from the rising waters for some years" (Saikia,

2019, p. 04). That relief proved fleeting, however, because the strategy contained a fatal flaw. Engineers treated the river as an entity to be aggressively tamed. The state pushed for "straitjacketing the river's braided beds into a single channel," driven by a technocratic belief that rigid control equated to safety (Saikia, 2019, p. 01). Consequently, by the 1960s, the river banks were loaded with embankments. The approach ignored a fundamental geomorphological reality that the river carries immense kinetic energy and extraordinarily heavy sediment loads. This negligence eventually brought immediate and severe consequences. Because of the river's sheer force, these structures often break down by the floodwaters. The long-term damage proved far worse than any seasonal flood. Saikia demonstrates that "the large-scale construction of embankments since the mid-twentieth century accelerated this ongoing process of floodplain transformation" (2019, p. 05). The river's natural ability to spread out and absorb water was permanently compromised, ensuring that "the narrative of the floodplains since then has largely been one of ruin and fatigue" (Saikia, 2019, p. 05).

The historical lesson is unequivocal: fighting a river's fundamental nature rarely ends well, and temporary fixes inevitably mutate into permanent ecological problems. These artificial barriers did not harmonize with the landscape; instead, they successfully "ruptured the interconnectedness between the river, floodplains, and highlands" (Saikia, 2019, p. 06). By cutting the watercourse off from the surrounding lands, the floodplains "now have tenuous links with their rivers" (Saikia, 2019, p. 05). This systemic alienation devastated local ecology and stripped economic vitality from riverine communities. Ultimately, the "concrete approach" offered a mere illusion of state control. Its fatal flaw was the permanent institutionalization of ecological vulnerability, proving that technocratic engineering alone is insufficient and must be strictly balanced with regional cultural knowledge and Earth-Knowledge.

4. 'Earth-Knowledge' and Cultural Archives as Climate Data

This section shifts to solutions by weaving indigenous narratives into climate strategies. If technocratic methods represent a failure of imagination, the Eastern Himalayas offer something different. Their cultural archives hold time-tested ecological knowledge. To understand these repositories, go beyond

simple descriptions of local folklore. Evaluate their strengths as ecological data storage and their vulnerabilities when modern state epistemologies pressure them.

4.1 Oral Tradition as Ecological Archives

A region's oral traditions serve as a cultural mode of preserving environmental knowledge, independent of Western scientific methods. The literary and ethnographic work of Mamang Dai is a notable instance of how these narratives function as highly resilient archives of ecology. In *The Legends of Pensam* (2006), Dai explores the worldview of the Adi community in Arunachal Pradesh. She defines "Pensam" as the "in-between"-translating it conceptually as "the hidden spaces of the heart where a secret garden grows. It is the small world where anything can happen and everything can be lived" (Dai, 2006, p. 05). Within this local framework, Dai documents the role of traditional oral epics chanted by the *Miri* (shaman). These rhythmic chants act as a deeply embedded form of storing indigenous wisdom. In a volatile landscape where seasonal floods pose a frequent threat of washing away physical maps and state infrastructure, the *Miri* meticulously record the genealogies of local flora, cyclical weather patterns, and pragmatic rules for coexisting with the forest in the form of "rhapsodies of time and destiny that he must guard" (Dai, 2006, p. 55). Dai's vision brings out the significance of these oral traditions as encyclopaedias of survival since their dynamic nature both endures and adapts to the essence of a community in a more holistic way than that of static, physical records. Her motivation for transcribing this cultural and ecological data was backed by a sense of personal urgency. Acknowledging the fragility of this medium, she notes in an interview, "Ours is an oral tradition you know, I was trying to meet people and collect and record these oral narratives. The small histories which were getting lost and when you talk to people even small things can trigger these memories off" (Malik, 2020, p. 124-125). Indeed, oral traditions carry a fundamental vulnerability in being entirely dependent on active memory and intergenerational transmission of knowledge. Factors like modern state education systems and out-migration of the youth severely disrupt this chain. When the younger generation disconnects from the linguistic, socio-cultural and geographical context of the chants, centuries of embodied ecological knowledge

face a threat of permanent erasure. Preservation of these oral narratives as a powerful ecological archive thereby depends entirely on a community's continued, intimate interaction with its shifting landscape amidst the growing environmental crisis.

4.2 Taboos as Conservation Laws: Temsula Ao and the Power of Genna

If Mamang Dai illustrates how Earth-Knowledge is recorded, the eminent Naga poet and ethnographer Temsula Ao demonstrates how it is actively enforced. Ao documents how indigenous myths operated not merely as performative folklore, but as strict, non-negotiable socio-ecological laws. In her rigorous ethnographic study, *The Ao-Naga Oral Tradition* (1999), Ao meticulously traces how practices frequently dismissed by modern frameworks as mere superstition functioned as highly effective conservation mechanisms. Central to this epistemology is the concept of "*Genna"* (Ao, 1999, p. 59), which refers to complex Naga taboos and restrictions that strictly govern when communities could hunt, fish, or harvest specific resources. A violation was never viewed as a simple legal transgression; rather, it invited profound supernatural consequences, ensuring that compliance was rigidly enforced by the entire community.

This dynamic proves that oral traditions function as living regulatory systems rather than frozen artifacts, evolving across generations precisely because they carry real consequences for communal survival. Central to this Earth-Knowledge is the strategic application of animistic beliefs—specifically, the reverence and fear of nature spirits, known as *Tsungrem.* In Ao Naga cosmology, Tsungrem refers to the "worship of *Lijaba*, the creator of the world" (Ao, 1999, p. 59). Specific ancient trees, deep river pools, and dense forest tracts are designated as the sacred abodes of these *Tsungrem*. To over-extract resources from these spaces is not a secular crime; it is a profound spiritual transgression—a *Genna*—that invites communal disaster.

The unparalleled power of the *Genna* lies in its internalized regulatory effect. Ao captures this ethos, noting that "our racial wisdom has always extolled the virtue of human beings living at peace with themselves and in harmony with nature" (Ao, 2006, p. 10). Unlike distant state forestry regulations, which require armed guards and are easily circumvented by corruption, the taboo acts as an impenetrable psychological boundary. It ensures

ecological compliance through the fear of spiritual retribution and communal shaming, transforming every individual into an active stakeholder and guardian of biodiversity. As Pinyar the widow in Dai's *The Legends of Pensam* succinctly observes, "Faith is everything" (Dai, 2006, p. 38).

However, this indigenous regulatory framework possesses a fatal ontological vulnerability when confronted with colonial and modern religious interventions, which actively attacked its foundations. In her poem "Blood of Other Days," Ao critiques how external epistemologies dismantled these ecological laws by "Declaring that our Trees and Mountains / Rocks and Rivers were no Gods" (Ao, 2003, lines 17-19) and dismissing native songs as "Nothing but tedious primitive nonsense" (Ao, 2003, line 22). When modern "book-knowledge" replaced Earth-Knowledge, the spiritual authority of the *Genna* collapsed. Ao mourns how this ideological shift "Allowed our knowledge of other days / To be trivialized into taboo" (Ao, 2003, lines 24-25). Once the landscape was stripped of its sacred status and the spiritual deterrent was removed, the terrain was left entirely unprotected against unrestrained capitalist extraction.

5. Integrating the Sacred and the Scientific

Bridging indigenous Earth-Knowledge with modern climate adaptation in the Eastern Himalayas means moving past hard engineering toward solutions that respect local cultural logic. The shift is not just technical but also psychological. Easterine Kire's novel *When the River Sleeps* shows this through its protagonist Vilie whose quest for the heart-stone reveals the eco-oriented perspectives of indigenous communities who see Nature as an active entity. Unlike a profit-driven person who tries to exploit natural resources for selfish purposes, Vilie knows the river gives its heart-stone only to those who seek it with respect. As Kire quotes, "The wisdom of the stone is more spiritual than physical. (Kire, 2014, p. 231). This archetype offers real strength for policy since it supports decentralized governance where "global initiatives on forest landscape restoration could connect to locally emerged landscape governance structures" (Oosten, 2013, p. 123). Bio-engineering rooted in cultural reverence can provide a model for sustainable long-term strategies to balance deeper ecological wisdom with practical, timely responses. Mishra and Pandey studies how "the combination of bioengineering and

small civil engineering structures represents a paradigm shift in disaster risk management, departing from traditional, rigid approaches towards flexible, nature-based solutions" (p. 53). Bio-engineering replaces rigid concrete with natural materials like native bamboo and vetiver grass to stabilize riverbanks. Instead of caging the rivers as concrete walls do, bamboo structures work as natural screens to slow water speed and let silt settle gradually. This approach also brings communities into the design process, turning vulnerable populations into active stakeholders. Bio-engineering as a method, however, carries its limitations. In addition to the demand of significant labour and constant communal maintenance, these models may often lack the immediate infrastructure that large-scale threats demand. For instance, it handles normal seasonal erosion well but may struggle against extreme mega-floods. This justifies the need for an integration of indigenous practices and scientific tools by combining solid hydro-science with local needs for lasting results.

6. Conclusion

The climate crisis in the Eastern Himalayas demands more than rigid and top-down technocratic solutions. This chapter shows how reliance on hard engineering like concrete embankments often makes ecological problems worse by ignoring how riverine landscapes actually work. We need an eventual shift that combines hydro-science with the deep environmental knowledge embedded in local cultures. Indigenous knowledge offers real tools here, like how the regulatory power of the Naga Genna represents centuries of community-driven strategies for living with dynamic landscapes. They are the working systems that have kept communities resilient through environmental change. The regional literature also reveals something scientists have often overlooked, i.e., the psychological weight of climate trauma. Terms like "solastalgia" and "hydro-anxiety" describe real suffering by flipping the narratives of the script on nature, moving it from a passive resource to an active force. So, what does this mean in practice? It clears the integration of sacred geography into actual work adaptation and supports community-led bioengineering instead of falling back to concrete every time. All of us must respect what local populations already know about their land. To sum this up, genuine climate resilience

in Northeast India requires a humanistic approach that treats both the landscape and its indigenous peoples as agents with a real stake in the outcome. It is only then that climate adaptation will work best when it becomes a negotiation with nature, not a conquest of it.

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16

Ecological Wisdom in the Folktales of Assam: A Study of Human–Nature Relationship

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ABSTRACT

This study offers to explore the human-nature symbiosis embedded in the folktales of different communities of Assam, situating them in a broader context of eco-critical theory and indigenous ecological epistemologies. In the era of environmental degradation, the study offers a critical insight about how indigenous storytelling in Assam encodes ecological ethics, community-based environmental knowledge and the ethos of interdependency with nature, thereby challenging anthropocentric hierarchies. Multiple folktales across different communities of Assam focus on non-human actors, such as animals, plants, rivers, and elemental forces—articulating a relational cosmology that informs traditional value orientations. For example, in folktales like "Tejeemola", "The Tale of the Kite's Daughter," "Tula and Teja," "Rowna-Rowni" (Bodo), "Midungdi-Nadungdi" (Dimasa), natural elements play pivotal roles in shaping the destinies of characters in the tales, denoting the cohesive interaction between human and nature.

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These folktales illustrate how the traditional knowledge system gives primacy to nature in the community life of Assam. Socio-cultural and environmental specificities present in different folktales tell us the story of sustainable cohabitation of Assam's agrarian, riverine, and forest-dependent people with nature, which could be crucial in the exploration of culturally grounded models of environmental sustainability in the present context. Methodologically, the study adopts an interdisciplinary approach informed by folklore studies, eco-critical theory, indigenous ecological epistemologies, and relational cosmology to interrogate the ecological wisdom present in the oral tradition of Assam. The study is particularly significant due to its potential to contribute to the ongoing debate on human-nature coexistence by reimagining human-nature relations through culturally embedded ethics of coexistence and ecological harmony.

Keywords: *Eco-critical Theory; Indigenous Ecological Epistemologies; Ecological Ethics; Relational Cosmology; Sustainable Cohabitation; Ecological Harmony.*

1. Introduction

Folktales could be considered not only as tales of myth, utopia or old stories rather could be seen as culturally embedded narrative which articulate societal values, negotiate societal norms and preserve collective memory. A.K Ramanujan in his *Folktales from India* has stated that a story is never just a story but a way of thinking (Ramanujan, 1991). Thus, folktales carry the thinking pattern of different generations through oral transmission of folk narratives. In the present era of consumerist development and anthropocentricism, the quest for ecological harmony emerging from indigenous knowledge system attracts enormous scholarly attention in recent time. Folktales if imagined through ecological perspectives could be the base for traditional knowledge, lived experiences, relational understanding or spiritual insight for considering the living and non-living world as interdependent. Folktales could operate as pedagogical instruments that transmit ecological consciousness and environmental ethics through myths, metaphor, allegories and archetypal narratives. Reimagining folktales through ecological lenses could decode the underlying eco-centrism of traditional lifestyle where human life was deeply interconnected and embedded with nature.

Folktales of different communities of Assam are harbinger of ecological wisdom which could function as ethical framework for cosmological worldview, ecological harmony and normative values for environmental sensitivity. Assamese folktales draw a picture of a traditional lifestyle where both nature and human maintain a relational harmony and ecology gets primacy as an end in itself not as a means for human consumption.

This study tends to reimagining of folktales of different communities of Assam through the lenses of eco-criticism and relational cosmology to uncover the indigenous ecological epistemologies. "Ecocriticism is the study of the relationship between literature and physical environment (Glotfelty, 1996). It studies how nature is represented in literature and how literature reshapes human understanding towards nature. It moves beyond anthropocentrism and perceives nature as an active force in itself. According to Richard Kerridge, ecocentrism is the opposite of anthropocentrism where at least as imaginative gesture ecosystem is placed at the centre rather than humanity alone (Keridge, 2006). Studying Assamese folktales from these perspectives unfolds the underneath symbiosis of nature and human in Assamese society of different time. On the other hand the study intends to portray indigenous relational cosmology in folktales of Assam. Relational cosmology challenges the narrative of atomistic and mechanical universe and foregrounds a model of interdependent relationship. In Assamese folktales, indigenous relational cosmology is quiet evident. For example stories like 'The tale of the Kite's daughter', 'The tale of the cat's daughter', 'Ou-Princess' in *Burhi Aair Sadhu* of Laxminath Bezbaruah and The Dolphin and the Crocodile (Mising), the story of Mayadongshri (Bodo), Midungdi-Nadungdi (Dimasa) could be seen with ideas of eco-criticism and relational cosmology which could help us reimagining Assamese folktales as forbearer of ecological wisdom and environmental ethics. This narrative will facilitate critical engagement with ecological conservation through culturally embedded indigenous epistemologies which recognizes the human-nature interdependency and reciprocity.

2. Theoretical Framework

This study relies on a qualitative, interpretive and analytical approach to study folktales of different communities of Assam. It primarily takes *Grandma's Tale* the English translated version

of Laxminath Bezbaruah's *Burhi Aair Sadhu* by Pallavi Barua and *Mothers, Daughters and Others* of Nandita Dutta, where folktales of different communities of Assam are available. Theoretically the study will rely on Eco-criticism and Relational Cosmology to analyze folktales from ecological perspectives. It intends to find out a culturally grounded model of environmental sustainability based on indigenous epistemologies.

3. Folktales in Assam and Ecological Wisdom

In Assamese society, childhood is intertwined with folktales which functions as transmitter of traditional cultural identity, moral consciousness, and collective memory. Folktales are foundational instrument of early socialization. Folktales of every community in Assam don't rely solely on human component rather natural elements take active part in it. Natural components like sun, moon, river, hills, forest, animals and tree etc characterized with active voice. Where some folktales represent active human-nature interaction ("The Tiger and the Crab", "Tejeemola", "The Tale of the Kite's Daughter", "Midungdi-Nadungdi", "Rowna and Rowni" etc), some other folktales represents only non-human components and narrates stories around them ("Fox and the Monkey", "Gongatoup" etc). The primary narrative of Folktales in Assam challenges anthropocentricism and propagate active interdependency between human and non-human world.

Burhi Aair Sadhu by Laxminath Bezbaruah contains multiple Assamese folktales that beautifully narrate ecocentrism and indigenous relational cosmology. In *Burhi Aair Sadhu*, folktales "collectively draw the picture of the traditional Assamese landscape which is seen endowed with the inseparable relationship between nature and folk life" (Sharma,n.d). In the folktale of "Tejeemola" (Bezbaruah 2011:34), the protagonist faced cruelty and got killed by her stepmother, but she didn't perish and transformed herself into different natural elements like bottle-gourd plant, citrus tree, lotus and bird and eventually survived and regained her life. The story symbolically puts light on the fact that human life is heavily dependent on nature and every natural element whether manifest in plant life or avian species has the capacity to nourish human life. "Tejeemola" also narrates how the protagonist got a voice and the means of resistance through nature which unfortunately she couldn't find

in her human form. This suggests, where in mechanical world justice is human driven but nature itself possesses the capacity of moral balancing. In "Tejeemola" nature rather than passive matter, is portrayed as an active participant in ethical domain. The folktale "The tale of a kite daughter" (Bezbaruah 2011:66) articulate relational cosmology embedded in Assamese folktales. In the story, the kite brought up the abandoned girl child into a beautiful woman and also managed her integration into human society. Here the kite is the symbol of nature's nurturing faculties and portray how avifauna positively interacts with human life. The folktale meticulously challenged the picturization of the kite as a predator species and asserts it as a protector and nurturing entity, propagating reverence towards all forms of life.

The folktale "Tula and Teja" (Bezbaruah 2011:74), reflects two contrasting kind of human ethics towards ecology. While son and daughter of *Alagi* (The first wife who was deprived due to the arrogance of the *Lagi*, the second wife) positively interacts with nature, *Lagi* was hostile towards nature which resulted in misfortune and misery. When *Lagi* deceptively transformed *Alagi* into a turtle, she nurtured her children being in that form itself. When *Lagi* got to know about *Alagi* being a turtle nurturing her children, she again deceptively made the turtle killed. But *Alagi* took the plant form and again pave the way for good fortune of her child. *Alagi's* son and daughter also interacted with nature positively by nurturing a bird which later helped the daughter get married to the king. The end of the story shows how *Lagi's* daughter eventually got killed due to her arrogance and disregard towards nature and on the contrary *Alaagi* despite being deprived, with positive correlation with nature eventually brought good fortune for her child. In this folktale nature is portrayed as an active force with the capacity to present rewards and punishment which suggest how ecology could respond accordingly with human conduct. Like "Tula and Teja" another folktale "Champawati" (Bezbaruah 2011:95) portrays the rewards and punishment based on human attitude towards nature. In "Champawati", a person has two wives *Lagi* (Favourite) and *Alagi* (Alienated). *Lagi* made her husband not to take care of *Alagi* and her daughter *Champawati* and alienated both deceptively. *Champawati* who was looking after her father's paddy field attracted a python's attention who wanted to marry her. *Lagi* being happy about the proposal advised her husband

to marry *Champawati* to the python expecting that the python would kill *Champawati.* But the python was a God in reality so instead of harming her he made her life prosperous. Being jealous of that, *Lagi* insists on marrying her daughter to a python. But ironically her daughter gets killed as it was a real python. This folktale denotes that while nature could bring all the good fortune to human society but its misappropriation and exploitation out of human greed could also end up in misery on the hand of nature itself.

The folktale "Ou-Princess" (Bezbaruah 2011:9) narrates the story of the miraculous birth of a girl out of an elephant apple. The mother of the elephant apple initially was in grief due to the unexpected abnormal birth of the elephant apple and denounced the fruit completely. But the fruit repeatedly returned to the mother and stayed near her. When a Prince saw the beautiful girl who secretly came out of the fruit to take bath, insisted upon marrying her. Eventually with the advice of a beggar, both were married. This story broadly signifies value of every natural element and their potential to bear prosperity and happiness. In the beginning of the tale, the fruit was considered valueless and seen as a symbol of misfortune, but later it proved contrary when the Prince understood the value of the fruit and took the risk of marrying a fruit, deviating from the societal norms. The story symbolically affirms that ecological elements like fruits are not merely a botanical thing but possess life-giving capacity. It tries to restore the importance of vegetation upon which fertility and agrarian lifestyle depends. In this folktale vegetation form of nature is portrayed with the quality of creativity, protection and regeneration.

Various folktales of Assam also illustrate how human and nature bonhomie results in prosperity and good-fortune for human. Folktales like "The Tiger and the Crab" (Bezbaruah 2011:25) and "The Tale of a Singora Fish" (Bezbaruah 2011:61) are the example of interspecies friendship which demonstrates relational cosmology. In the folktale of "The Tiger and the Crab" the primary human character after rescuing himself from the tiger took shelter on a tree beneath of which was the retreat of the wild buffalos. Here the tale narrates a reciprocal relationship between the man and the wild buffalos where the man regularly cleaned the habitat of the buffalos and in return he got food and protection from them. Due to this bonhomie of the man

and buffalos, later the man could become a king by marrying the only daughter of the former king. Similarly in the folktale, "The Tale of a Singora Fish" there is a farmer whose fortune was completely changed due to his kindness towards the fish. The farmer instead of killing the fish, gave shelter to the fish and the fish in return looked after his cows. Later the fish revealed his divinity and made the life of the farmer prosperous. Both the story explains how the well being and fortune of human being, does not depend upon mastery on nature, rather it depends upon mutual respect and co-habitation. Both the stories portray ethical alignment with nature which articulates a relational cosmology where prosperity arises from interdependency with nature.

Some folktales like "The Monkey and the Fox" (Bezbaruah 2011:5) and "Gangatoup" (Bezbaruah 2011:49) works as allegorical narratives through which nature guides humanity. These folktales reflect the consequences of greed, deceit and pride through examples from animal and aquatic world. In "The Monkey and The Fox", initially because of his impulsive overconfidence and greed the Monkey deceived his friend fox. But later the fox with the help of his wit and wisdom taught the monkey a lesson and made his life miserable. The fox's triumph could be seen as an allegorical moral framework for human which could make human aware of the consequences of greed and cunning behavior. On the other hand in the tale "Gangatoup", when the *Gangatoup* fish was praised by his aunt, he felt that he could touch the heaven with his bare hands and swelled in pride. The more he took pride on his aunt's words the more swollen up his belly became and consequently his belly burst out making a big sound. This folktale allegorically displays the consequences of excessive pride. In both the folktales, nature becomes a stage for human ethical arena that shows us how ecological elements could be used for moral guidance and for ethical living.

Apart from folktales mentioned in the *Burhi Aair Sadhu,* the local folktales of diverse tribe communities of Assam also presents the same narrative of relational cosmology and ecological wisdom. These people belonging to different tribes are mostly forest dwellers and their livelihood vastly depends on forests, hills, rivers and animals etc. In their folktales reciprocity and interdependency with nature is quiet evident.

In his book on Kachari Folktales, JD Anderson narrated how water and lives in water were widely respected by Kachari People (Anderson, 1895). In the story "How the rivers were made", water resources are portrayed as natural resources which the people had very little right to mingle with (Narzary, 2024). In the story, the deity *Sri* created river to facilitate migration of fish into Brahmaputra. In return, the fish bestowed medicinal knowledge upon the deity. This shows how indigenous folktales portray creation of natural elements like river based on relational cosmology. In the same way the Mising folktale "The Story of Cloth" (Dutta 2012:125) presents reciprocal relationship between nature and human. The story portrays the origin of cloth on earth. When the Mising youth *Kowensa* got the mysterious fish in *Kamlang* river, he spared the life of the fish and then the fish later transformed into a beautiful women who could weave cloths. This act of kindness of *Kowensa* towards nature resulted in arrival of cloths on earth. This folktale tries to portray the skill of weaving as ecological memory denoting nature's creative faculty.

In the Dimasa folktale "Midungdi-Nadungdi" (Dutta 2012:142), a multilayered narrative of human and animal interrelationship could be found. The story narrates how the old man sustained his life on his domestic cow and after their death, seven dogs emerged out of the burial site of the cow whom the tale described as brother of the old man's son. The seven dogs worked as the protector and provider of the old man's son denoting nature regenerative quality and ancestral continuity of friendship between human and animal. In the same story when the dogs killed a deer and out of the meat of the deer a beautiful woman emerged to whom the old man's son got married. But when the women was scolded angrily by her husband she transformed into an elephant and left for the forest denoting how mismanagement of nature could create rupture between human and nature.

The Rabha folktale "The Story of the Peacock and the Peahen" (Dutta 2012:181) beautifully articulates relational cosmology based on ecological reciprocity. In the story the *Myna* bird's declaration that "I am not a *myna*, but a goddess from heaven" dismisses the imaginative boundary between divine, human and avian form of the nature. This declaration pushes the idea that every form of nature could potentially be seen as divine

manifestation on earth. The mother of the protagonist man refused to kill the bird which later proved fruitful for her son when the bird later completetely transformed into a beautiful woman and married her son. Even after the ill-fated intervention from the sisters of the goddess which transformed her husband into a peacock, even then the goddess refused to leave him and transformed herself into a peahen and remained together forever. This story clearly portrays relational entanglement and unbreakable dependency between human and avian world.

Folktales of different communities from Assam imagine birth of different natural species out of human-nature interactions. As shown above in the folktale of "The Peacock and the Peahen", Rabha people believes it as the birth story of peacock and peahen. In the same manner a Mising folktale "The Dolphin and The Crocodile" (Dutta 2012:120) narrates the birth story of dolphin and crocodile. In this story when the young girl Tamang was forced to marry another boy instead of her lover, she jumped into a river and out of agony her lover followed her and also jumped into that river. But miraculously, instead of being killed Tamang transformed into a dolphin and her lover became a crocodile. Similarly, some folktales also carry folk narratives where natural phenomena are also believed to be started due to human-nature interactions. For example the Bodo Folktale "Rowna and Rowni" (Dutta 2012:106), describes how natural events like lightning and thunder started from mutual transformative quality of human and nature. When *Rowni* was forced to marry her brother *Rowna* against her wish, she transformed into lightning and *Rowna* followed her and became thunder. Because of this, there is a folk belief that thunder follows lightning as *Rowna* is still chasing *Rowni* even in their transformative form. These types of folktales portray, how indigenous people of Assam relates their daily life with nature affirming positive recognition of relational cosmology between human and non-human world.

4. Conclusion

The crux of the above analysis clearly denotes that folktales of different communities of Assam shouldn't be considered as mere medium of entertainment or old imaginative stories. Rather, the foregoing analysis presents the idea that indigenous folktales could work as culturally grounded moral framework

for ecological wisdom. Ontological fluidity between human and non-human world in folktales of Assam challenges the narrative of anthropocentrism and propagate relational co-existence between human and non-human world. These folktales clearly affirm ecocentrism where natural world possesses moral agency. Natural world in folktales of Assam takes active part in human life and react according to ethical or unethical conduct. We could clearly conclude that Assamese folktales put human within, rather than above ecology. And this narrative could work as intergenerational moral framework for ethical conduct towards the ecology and affirm that ethics of ecological sustainability are generationally and grounded in indigenous epistemologies.

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17

Ecological Perspectives in Assamese Indigenous Storytelling

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ABSTRACT

Literature and the environment are intricately intertwined, as the natural world often serves as both context and catalyst for human imagination. Specifically in folk literature the ecological surroundings shape narrative forms, motifs and moral imagination. Folk literature refers to the oral and traditional expressions of common people. Through its multiple genres, such as folk tales or storytelling, myths, folk songs, proverbs, etc., it reflects various ecological perspectives of traditional societies. Assamese folklore is a simple and collective creation of the indigenous people living in rural areas of Assam. These oral stories reflect the profound connection between the morals, beliefs, social norms, and environmental wisdom of the society. The nature of Assam is clearly expressed in the folk tales. In the collections of folk tales by the prominent writer Lakshminath Bezbaruah such as Kaka-Deuta aru Nati-Lara, Burhi Aair Xadhu and Junuka the depiction of nature is very clear. In this folklore, animals also speak and behave like humans.

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Nature in Assam's Indigenous storytelling is portrayed as a vital participant shaping spiritual beliefs, emotions, and the rhythms of survival. The ecological awareness inherent in the community's mindset has been instrumental in fostering a sustainable relationship between humans and their natural environment. Studying folklore through an ecological lens can help to explore how the indigenous people of Assam traditionally perceive, conserve, and interact with their surroundings. This study will explore the ecological perspectives inherent in Assamese indigenous storytelling and its potential impact on the environment.

Keywords: *Folk Literature, Indigenous Storytelling, Ecological Perspectives, Environmental Wisdom, Lakshminath Bezbarua*

1. Introduction

Nature and folk literature share an inseparable bond as the roots of folk narratives lie deeply embedded in the natural world. Folk literature, born from the collective consciousness of rural and indigenous communities, reflects their intimate relationship with the environment that sustains them. The rural life of Assam is profoundly shaped and sustained by nature, illustrating a harmonious coexistence between people and their surroundings. Assamese indigenous storytelling embodies a deep ecological consciousness rooted in the symbiotic relationship between human life and the natural world. The Assamese people generally use a specific term to refer to these narratives. The term is generally known as *Xadhukatha*. *Xadhu* means morally good, and kotha means story. Thus, *Xadhukatha* literally means "a story that teaches morality or goodness." In earlier times storytelling in Assamese society served as a means of imparting moral conduct, community values, and life lessons to the younger generation. Elders, grandparents, or village storytellers would narrate these tales in the evenings, often concluding with a moral message. Consequently, people came to associate these tales with Sadhu (goodness) and hence they were called *Xadhukatha.* The folklore researcher Dr. Leela Gogoi mentions that *Xadhukathas* are reflections of people's lives. These are about the mind, society, folk beliefs, and intellectual activities of a group of people. It has a high place and value in the history of literature of all nations of the world (Gogoi, 2001).

The prominent Assamese writer Lakshminath Bezbarua played a vital role in preserving and enriching Assamese folk literature, particularly the *Xadhukatha* tradition. Bezbarua collected numerous folk tales from various parts of Assam and published them in his famous collections, such as *Burhi Aair Xadhu*, *Kaka-Deuta Aaru Nati-Lara*, *Junuka* etc.

This study examines the ecological perspectives embedded in Assamese indigenous storytelling and their significance in shaping environmental awareness. The discussion is structured around five key areas addressed in the succeeding sections.

2. Nature as an Active Agent in Folklores

In Assamese folklores nature is not merely an external setting but it acts as a living presence. The rivers, forests, mountains and animals often appear as living characters or spiritual beings who communicate with humans. This close relationship reflects the indigenous worldview of harmony between humans and nature where every element of the environment is regarded as alive. For instance, in the story *Chilanir Jiyekor Xadhu* (The Story of the Swallow's Daughter) a king, disappointed at the birth of a daughter instead of a son, orders the infant girl to be thrown into the water. Abandoned by her own family, the child is rescued by a compassionate swallow. The bird carries the baby to its nest and nurtures her with care and affection. As the girl grows up, she begins to regard the swallow as her mother and protector. Through divine blessing the swallow grants the girl magical powers and extraordinary beauty. One day, a merchant passing by notices the girl and is enchanted by her grace. He asks for her hand in marriage. The swallow, though saddened willingly consents. Before the girl departs, the swallow teaches her a sacred mantra. Whenever she utters it, the swallow appears instantly.

When the human world rejects the infant, nature intervenes through the swallow. The bird actively saves and raises the child taking on the role of a compassionate guardian. The swallow's motherhood replaces human cruelty. Here, nature functions not as a passive backdrop but as an active agent capable of nurturing human life.

Similarly, in the story *Burha Burhi aru Xial* (The Old Couple and the Fox) an old man and his wife cultivate taro roots in their field.

One day, a group of foxes visits them and engages in friendly conversation. Pretending to be wise and helpful, the foxes advise the old couple to boil the taro roots before planting it, claiming that only then it would grow faster. Trusting their words, the couple follows the suggestion. At night, the foxes return and eat all the boiled taro roots, leaving the couple deceived. Realizing the trick, the old man and woman decide to take revenge. They spread a false message that the old man has died, hoping to lure the foxes into their trap. When the foxes gather at their home, the couple attacks them and beats them severely. Enraged and humiliated by them, the foxes vow revenge and begin to follow the couple with the intention of eating them. Later, when the old woman visits her daughter's house, the foxes again appear to attack her. At that moment, she calls out to her dogs—Koli and Bogi—who come running to protect her and drive the foxes away.

Here, nature functions as an active moral and social agent. The foxes' cunning exposes human vulnerability and the danger of blind trust while the dogs' loyalty restores balance and justice. This dynamic interaction between humans and animals reflects an indigenous ecological worldview in which every creature participates in maintaining moral and environmental harmony.

3. Indigenous Conceptions of Environmental Ethics

Assamese folk tales are deeply rooted in the beliefs of the indigenous peoples of Assam. Many elements of nature are often regarded as manifestations of divine power, reflecting a deep spiritual connection between humans and the natural world. Most of these stories emphasize on a give-and-take relationship between humans and nature. Acts of greed, exploitation or disrespect towards nature often result in punishment, while kindness and gratitude are rewarded and blessed by natural forces. For instance, in *Burhi Aair Xadhu*, there is a story titled *Mekurir Jiyekor Xadhu* (The Story of the Cat's Daughter). In this tale, a cat interacts with her landlady as if she were a woman. Both the cat and the landlady become pregnant at the same time. The pregnant cat longed for some fish and asked the landlady to share some with her. The landlady, also craving fish, told the cat to bring her some instead. The cat obediently brought fish every day and offered it to the landlady. However, the landlady deceived her by eating all the fish herself. Angered by this

betrayal the cat cursed the landlady declaring that she would give birth to the cat's kitten. Soon after, the woman indeed gave birth to the cat's kitten. On the other hand, in the story *Bhekulir Xadhu* (The Story of the Frog) nature once again appears as a benevolent and active moral force. The tale narrates how a frog blesses an old couple for rescuing it. One day, while fishing the old man caught a frog in his *jakoi* (a traditional bamboo fish trap) and intended to kill it. The frightened frog pleaded for its life and promised to help the old man in return if he spared it. Moved by compassion, the old man released the frog. Thereafter, the frog became a faithful helper to the old man, assisting him in every task. One day, the king of the land seized the old man's cows. In response, the brave frog confronted the king and defeated him in battle. Astonished by the frog's courage and strength, the king declared the frog the ruler of half of his kingdom. This story highlights the indigenous belief that kindness towards even the smallest creatures invites divine reward and protection.

Many Assamese folk tales originate from animistic traditions in which every element of nature is believed to possess a spirit, often referred to as *devatas* or *ai*. This perspective promotes harmony and coexistence between humans and the natural world rather than human dominance over it. Furthermore, the rituals, taboos and customary practices associated with these beliefs serve as indigenous systems of ecological regulation. In the story *Champawati*, it is shown that the common people of Assam believed that certain animals, like the python could appear as divine beings or *devatas.* In this tale, a python appears as a divine soul and wishes to marry a young girl named *Champawati*, the daughter of a rich man. Her parents were frightened by this strange proposal but the marriage finally took place. After marrying her, the python gave *Champawati* many golden ornaments showing his divine nature. One day, *Champawati* met an old woman who told her that the python was actually a deity. However, the old woman was a demoness who wanted to eat *Champawati*. Knowing this danger, the python gave *Champawati* a magic ring that protected her from harm. This story shows that Assamese people believed nature to have divine power. The python is seen not as a dangerous creature but as a protector, showing the close connection between humans and nature.

Folk narratives often serve as moral instruments that teach virtues such as truth, kindness, humility and justice through

symbolic and imaginative storytelling. Many tales extend this moral vision to the natural world, emphasizing the importance of living in harmony with nature and all forms of life.

In a famous Assamese folklore, *Bandor Aru Xiyal* (The Monkey and the Fox) tells the story of two animals who become friends in the forest. They decided to steal food from travellers passing by the road. Working together, they collect food to eat. However, when it is time to share the food, both the monkey and the fox try to cheat each other. Therefore their friendship ends in conflict and both remain hungry. This story reflects human nature through animal behaviour. Morality of this story is that greed and selfishness destroy friendship and harmony. True cooperation and honesty are essential for peaceful living.

4. Symbolism and Motifs

Assamese folklore is rich in symbolic meaning and motifs that reflect the cultural imagination, spiritual world view and moral consciousness of the Assamese people. Symbols and motifs serve as tools through which the community expresses its relationship with nature. In Assamese folk stories, elements of nature like rivers, trees, animals, birds and the sun have deep symbolic meanings. The river is often seen as a symbol of life and purity. Animals such as the tiger, elephant and serpent stand for strength, protection or divine power. Birds like the swallow and the dove represent kindness, guidance and the close relationship between human and nature. Magical objects, talking animals and divine beings often appear in these stories as special motifs that link the human world with the spiritual world. In *Chilanir Jiyekor Xadhu* (The Swallow's Daughter), the swallow symbolizes motherly love and protection, as it saves and raises the abandoned child, showing nature's role as a compassionate guardian. Similarly, in *Bhekulir Xadhu* (The Frog's Story), the frog represents courage and gratitude; after being spared by the old man, it helps him in return and defeats the unjust king. It reflects nature's moral justice. In *Champawati*, the python symbolizes divine presence and protection, proving that even wild creatures can embody sacred power. The story *Bandar aru Xial* uses animals and their actions as symbols of human behaviour. The fox's cleverness and the monkey's foolishness teach that intelligence must be guided by honesty and greed always brings loss.

Symbols and recurring motifs are not only to entertain but also to express the community's spiritual connection with the natural world and its deep ecological wisdom. Through its symbols, Assamese folklore teaches that humans and nature are connected and must care for each other.

5. Metamorphosis and Environmental Continuity

Transformation or metamorphosis is an important theme in Assamese folk stories. It shows the close connection between human life and the natural world. In many of these tales, humans, animals and parts of nature change their forms, expressing the belief that all living beings are linked in a continuous cycle of life and spirit. The story of *Tejimola* is a strong example of this idea. After being killed by her stepmother, *Tejimola* takes new forms—as a lotus, a gourd plant and a fruit tree. Her rebirth through nature shows that goodness and purity cannot be destroyed; they live on through the environment. Similarly, in *Chilanir Jiyekor Xadhu*, the swallow becomes a divine mother who protects a human child, showing the bond between humans and animals.

In the story *Oukuwari,* the younger queen of a king gives birth to an elephant apple *(ou tenga)*. Feeling sorrow and shame, she throws it away. The fruit drifts to the riverside, where it later transforms into a beautiful girl. As time passes, a prince discovers her and eventually marries her. The story of *Oukuwari* carries rich symbolism rooted in Assamese folklore and nature-centric beliefs. The elephant apple symbolizes fertility, rebirth and the hidden creative power of nature. Its transformation into a girl represents the idea that life and beauty can emerge from unexpected and discarded forms. The river, which nurtures the fruit until it transforms, signifies purification and the continuity of life. Together, these symbols reflect the indigenous worldview that nature is not passive but actively participates in the cycle of creation, protection and renewal. The tale emphasizes the belief that nature has the power to restore balance and reward purity, even when human society fails to recognize it.

In the story *Kanchani*, an old couple had seven sons. After the couple's death, the six elder brothers got married. The youngest son was kind and innocent, and his brothers deeply loved him. However, their wives became jealous of this affection and, out of

envy, transformed the youngest brother into a dog by uttering an evil mantra. The dog wandered from place to place in sorrow until one day he met a compassionate girl named *Kanchani*. Moved by his suffering, *Kanchani* cared for him tenderly. When she bathed the dog, he miraculously transformed back into a handsome young man and the two were united in marriage.

The story of *Kanchani* holds profound symbolism. The transformation of the young man into a dog represents the moral fall caused by jealousy and the misuse of power. The dog, a symbol of loyalty and innocence, embodies the purity of the soul that survives even after being wronged. On the other hand, *Kanchani* symbolizes compassion, purity, and the redemptive power of love. Her act of washing the dog can be seen as a symbolic purification—a restoration of truth and virtue. The tale reinforces a key moral theme in Assamese folklore: that goodness, though temporarily suppressed by evil forces, ultimately triumphs through kindness and moral integrity. In the Assamese folk story *Tula aru Teja*, a farmer had two wives and each had a daughter. The elder wife's daughter was Tula and the younger wife's daughter was *Teja*. Tula's mother was extremely jealous of *Teja* and her mother because *Teja* was kind, beautiful and loved by everyone. Out of envy, Tula's mother used evil magic to harm them. As a result, *Teja's* mother was transformed into different forms of nature — a tortoise, a flower and a sour tree. Even after these transformations, Teja's mother continued to protect and guide her daughter through magical powers. Her spirit lived in these natural forms, helping *Teja* through every difficulty. Later, when a king passed by, he was drawn to *Teja's* beauty and goodness and married her, making her the queen. On the other hand, because of her cruelty and jealousy, Tula met a tragic end. The repeated transformation of *Teja's* mother into a tortoise, a flower and a sour tree represents the theme of metamorphosis — the idea that life continues through different forms in nature. It reflects the Indigenous Assamese belief that the soul is connected to the natural world and that goodness never truly disappears but changes form to continue its purpose.

These transformations reflect the belief of the indigenous people of Assam that nature and human life are deeply connected and that moral and spiritual energy continue through the natural world.

6. Insights for Contemporary Environmental Discourse

In today's world, environmental issues have become one of the most important global concerns. Global issues like climate change, deforestation, pollution, and the loss of plants and animals have gained the attention of people everywhere, including scholars, activists, and political leaders. Modern environmental thinking focuses on protecting nature, using resources wisely, and living in a balanced way with the environment. It also questions the harmful effects of industrialization and consumerism, which have often led to the misuse and destruction of nature.

Assamese Indigenous storytelling offers profound ecological wisdom that directly informs contemporary environmental discourse by articulating a deeply interconnected, non-anthropocentric worldview. Key lessons are discussed briefly:

- **Harmony between Humans and Nature**

  Assamese folk stories highlight the close relationship between people and nature. They teach that when humans live in balance with the natural world, both can thrive in peace and harmony.

- **Respect for All Living Beings**

  In many stories, animals, birds, rivers, and trees are shown as living beings with feelings and spiritual value. This reflects the belief that all parts of nature deserve respect and protection.

- **Consequences of Greed and Exploitation**

  The tales often show that greed, cruelty, or misuse of nature leads to suffering and punishment. These stories remind us that harming the environment brings harm to human life as well.

- **Rewards for Kindness and Compassion**

  When people show kindness to animals or care for nature, they are often blessed or rewarded. This teaches that compassion and gratitude towards the natural world lead to positive outcomes.

- **Nature as a Source of Moral Lessons**

  Nature in Assamese folklore is not just a background but a teacher. Rivers, forests and animals often guide humans to learn moral values such as honesty, humility and thankfulness.

- **Spiritual Relationship with Nature**

  Assamese Indigenous storytelling views nature as sacred. It shows that the environment is not only useful for survival but also holds divine energy that connects humans with the spiritual world.

- **Cycle of Life and Renewal**

  Stories like *Tejimola* express the belief that life continues through transformation. The natural cycle of birth, death and rebirth reflects the constant renewal found in both human life and nature.

7. Conclusion

Based on the preceding discussions, it can be concluded that Assamese Indigenous storytelling carries profound ecological perspectives. Ecological perspectives and indigenous storytelling of Assam are deeply interlinked because both arise from the same worldview that sees nature and human life as inseparable. The indigenous communities of Assam have long lived in close relationship with their environment, depending on rivers, forests and fields for survival. This close bond with nature is reflected in their stories, songs, and oral traditions. These folk narratives express the community's deep respect for nature and emphasize moral harmony between humans and the environment. Through stories such as *Tejimola, Bhekulir Xadhu, Chilanir Jiyekor Xadhu* and *Champawati* we find recurring themes of harmony, transformation, compassion and moral justice—all rooted in ecological awareness. The tales teach that respect for nature ensures balance and prosperity, while greed and cruelty invite destruction. Through symbolic characters, transformations, and moral lessons, they promote values of balance, compassion, and sustainability, which remain highly relevant in today's environmental discourse. In the context of today's environmental challenges, these traditional tales hold timeless relevance. They remind modern society that protecting nature is not only a practical necessity but also a moral and spiritual duty. Thus, Assamese Indigenous storytelling serves as an important source of ecological awareness, inspiring sustainable living and reaffirming the sacred bond between humans and the natural world.

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18

Northeast-Centric Assamese Travel Literature: With Special Reference to Leela Gogoi's *Simantar Mati Aru Manuh*

Rubi Bora[1]

ABSTRACT

This chapter looks at the growth of travel writing in modern Assamese literature. It traces the genre from its early beginnings in the 19th-century journal Orunodoi to its steady rise after India's independence. While Assamese writers have traveled and written about many places in India and abroad, books focused specifically on the Northeast are fewer in number but deeply valuable. The Northeast is a unique region with eight states, high mountain ranges, rich wildlife, and borders shared with several countries. Writers who traveled through its forests and along its rivers captured important details about local life that might otherwise be forgotten. A central figure in this writing is Leela Gogoi. His books stand out because he did not just describe the scenery; he wrote about the daily lives, cultures, and economic struggles of people living along the borders. This chapter shows how Gogoi's work helped turn simple travel stories into valuable records of the region's people, land, and history.

Keywords: *Assamese Literature, Travel Writing, Leela Gogoi, Orunodoi, Northeast India*

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1. Introduction

Travel literature is a significant genre within prose writing. The word "travel" literally means "to wander." In English, the act is called travel, and the person who undertakes it is a traveller. Travel narratives are created to preserve the experiences of a journey. When these accounts are enriched with literary elements and stylistic diversity, they are transformed into travel literature. This genre offers profound insights into the educational, social, cultural, economic, political, geographical, and historical aspects of a region and its people. Since ancient times, people have travelled across the world, fostering communication between diverse cultures. Although the modern internet provides extensive information at our fingertips, the innate desire to see the unseen and know the unknown keeps the passion for travel alive. Consequently, travel literature as a literary genre continues to gain importance and appreciation.

Assamese literature boasts a rich collection of travel writing. While travel accounts appear in ancient texts, the post-independence period witnessed particular growth in the diversity of Assamese travel literature. Among the writers who imparted fresh momentum and originality to this genre is Leela Gogoi. Travel literature is inherently personal, expressing the author's spontaneous passion and joy, allowing readers to visit places vicariously through direct experiences. The fluent portrayal of a journey brings the reader immense enjoyment. Therefore, literary quality is essential for enriching travel writing. This genre requires sensitive reflection, subtle observation, and a poetic beauty of language.

The *Assamkosh* describes travel literature as follows:

"Travelling the country is not possible for everyone. Studying travel literature can easily give people interested in travel a taste of travel. But the author must be able to incorporate into this literature the qualities, values and perspectives that can compensate for this desire" (Bharali, 2005, p. 343).

The history of Assamese travel literature, while not ancient, has its roots in oral traditions. Its early seeds can be traced to ancient and historical elements. Oral folk tales, folk songs, proverbs, and fairy tales often describe travel experiences. An Assamese folk saying, *"Nana thai fube ji nana kotha hike he"* (A boat that sails to many places hears many stories), captures this spirit.

Fairy tales speak of merchants on trading voyages and kings on hunting expeditions, with characters such as Phulkonwar and Manikonwar travelling on mythical steeds. The *Nawariya Geet* and *Baramahi Geet* recount merchants embarking on long trade journeys. Similarly, Madhava Kandali's Ramayana and the works of Sankaradeva contain accounts of travel and exile. Sankaradeva structured parts of the Kirtan Ghosa based on his experiences in Odisha.

Medieval Assamese literature also includes travel-related material. During the Ahom period, emissaries were sent to other kingdoms for political or military purposes. Narratives in the *Buranjis* (historical chronicles) are notable contributions. *Brindawan Charitra*, written by Bam Mishra during the reign of Ahom king Jayadeva Singh (1645–1663), is considered the first travelogue in Assamese literature. *Tripura Buranji (*1724), written by Ratna Kandali and Arjun Das Bairagi, also falls within this genre, as it describes geography, tribes, folk culture, and architecture (Borah, 2017, p. 288). Accounts in the Guru-Charit literature, particularly those describing Sankaradeva's travels, are also relevant to this genre.

2. Development of Assamese Travel Literature

Modern Assamese travel literature began to take a recognizable shape in the nineteenth century. Its development can be divided into the pre-independence and post-independence periods.

2.1 Pre-Independence

The earliest form of Assamese travel writing appeared in the pages of Arunodoi magazine. A letter from a student named Lucy Haydon, published in the August 1849 issue under the heading "Americaloi Juwa Ejon Nagaon Schoolor Satror Pora Ami Ei Jatrar Sithi Palo" (A Letter About This Journey from a Student of Nagaon School in America), contains the germ of Assamese travel writing.

A major early example is the travel account published from the fourth to the eighth issues of the magazine Jonaki in 1890. Anand Chandra Agrawal's travel story Brahmyatrir Diary (1894), published in Jonaki, describes his journey to Burma. Another significant contribution is Gyanadaviram Barua's Bilator Sithi, published in Bahi in 1909.

2.2 Post-Independence

The genre expanded rapidly in the post-independence period, driven by wider social changes and growing opportunities for travel within India and abroad for education, diplomacy, and cultural exchange. Post-independence Assamese travel writing can broadly be divided into domestic and overseas accounts. In keeping with the focus of this chapter, the following section examines domestic travel literature.

2.2.1 Domestic Travel Literature

This category includes:

- **Pilgrimage Writing:** Subrata Baruah's *Himatirtha Badrinath*, Srinathdev Goswami's *Bharat Tirtha Kahini*, and Nirupama Kataki's *Devbhoomi Badrinath Pora Devi Kanyakumari*.
- **General Travelogues:** Harinarayan Dutta Baruah's *Bharat Bhraman*, Rohini Kumar Kakati's *Himkanya*, and Debendra Nath Bora's *Rajatarangini Kashmir*.
- **Northeast-Centric Travelogues:** Laksheshwar Sharma's *Misimi Paharor Rono Hinga*, Leela Gogoi's *Simantar Mati Aru Manuh*, and Arupa Patangia Kalita's *Pahar, Nodi, Sagar Aru Manuh*.
- **Wilderness and Adventure Travel:** Soumyadip Dutta's *Aranyatur Bhraman Kotha* and Pranay Bordoloi's *Himalayar Shikhare-Kandarare*.

Among these, Leela Gogoi's *Simantar Mati Aru Manuh* stands out as a foundational Northeast-centric work.

3. Overview of the Book *Simantar Mati Aru Manuh*

Leela Gogoi's book is structured into multiple sections such as *Simantar Kotha, Simantar Janmologno, Hukang Upatyakat Nidhan, Monor Manuh Monpa, Adi Jonojati, Misimir Bisar Paddhati, and Khamti Rajyoloi.* These chapters contextualise various border regions of Northeast India. Gogoi writes in a distinctive, evocative style, vividly portraying the geographical, cultural, economic, and political aspects of the region.

3.1 Geographical Aspects

The book opens with references to the snow-clad Himalayan ranges, situating Northeast India within this grand geographical expanse. It mentions rivers such as the Chiang, Siam, Dihing,

Dibang, and Dikrang. The Northeastern Frontier is described as a mountainous region of approximately thirty thousand square miles, bordered by Tibet and China to the north, Burma to the east, the plains of Assam to the south, and Bhutan to the west. It is a land of diverse tribes, lush forests, rivers, waterfalls, and wildlife. Gogoi poetically asserts that the land, water, and dreams of the border are intertwined with the identity of the nation.

3.2 Cultural Aspects

The book offers rich depictions of the cultural mosaic of the border region. Gogoi observes that the inhabitants have lived for centuries with distinct customs, manners, and languages. He categorises the region into Buddhist, Naga, and multi-colored cultural zones, describing each in detail. In the Tirapor Tangsa section, he highlights the Tangsa community's skill with bamboo, their marriage system, folk beliefs, and cuisine. The lives and cultures of the Monpa, Adi, Dafla, and Naga tribes are also vividly presented. Gogoi notes their contributions to Assamese culture, including influences visible in Bihu.

3.3 Political Aspects

Gogoi discusses the political structures of the border communities, such as rural administration and traditional governance systems like the village councils among tribes such as the Aka. These councils adjudicate disputes ranging from minor quarrels to serious crimes. The section *Gonotrantar Laikhuta* outlines the principles, public decision-making, criminal trials, and parliamentary procedures of the Galong tribe. The book also covers the Misimi justice system, Inner Line regulations, and historical accounts of various local rulers.

3.4 Economic Aspects

The book describes economic practices, including the tradition of paying *ga-dhan* (livestock) as dowry among tribes like the Tangsa and Aka. This may include items such as swords (methon), iron knives, clothes, and ornaments. The Monpa community is portrayed as agriculturalists and livestock rearers, while the Adi tribe practices jhum (shifting) cultivation to address economic needs.

Gogoi's prose often becomes poetic in describing the natural beauty and cultural diversity of the region. He writes of rivers

"dancing down the mountains" and describes the people of evergreen landscapes as having minds that are "evergreen."

4. Conclusion

In Simantar Mati Aru Manuh, Leela Gogoi skilfully highlights the harmony between the hills and the plains of Northeast India. By weaving together geography, culture, politics, and economics with a refined literary sensibility, he elevates an ordinary travel account into a significant work of travel literature. Effective travel writing must be both informative and enjoyable, thereby enabling readers to acquire knowledge while mentally experiencing the places described. The richness in region-centric themes and artistic expression makes Gogoi's Simantar Mati Aru Manuh stand as an exemplary contribution to Assamese travel literature.

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19

Urban Wastewater Management in Guwahati- an untapped domain

Zeba Zoariah Ahsan[1]

ABSTRACT

Water, as much as it is an elixir of life, is liquid wealth too. Urban water management is one of the cornerstones in modern-day governance models. There are many facets under the gamut of urban water management that need an interdisciplinary approach with multiple stakeholders in a changing climate. Wastewater management is one area that has been under-researched and largely unexplored in the context of NE India in general and Assam in particular. As it is not a part of the water discourse yet, urgent intervention is required with rising population and changing consumption patterns, especially at a time when pollution is so visible to the eyes. It becomes even more pertinent at a time when government flagship missions are centred around cleanliness, building of smart cities, housing, and energy. Wastewater thus becomes a core component of the circularity of water in the context of sustainable development. Rethinking water uses and wastewater reuse with the right mix of policymaking and technological intervention is the need of the hour. Wastewater management is deterministic of public health at large, as water quality parameters are not the same throughout different stretches of a city.

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This is largely due to different types of wastewaters generated depending on context. Therefore, the role of sewage treatment plants and fecal sludge treatment plants becomes crucial to treat effluents from industries and sewage from residential areas. Lack of research, literature, political will, infrastructure, misgovernance, and paucity of funds all form a part of the problem. As and when this unexplored area of wastewater gains traction, it will solve many sanitation woes.

Keywords: *Wastewater, Water Governance, Climate Change, Circularity, STPs*

1. Introduction

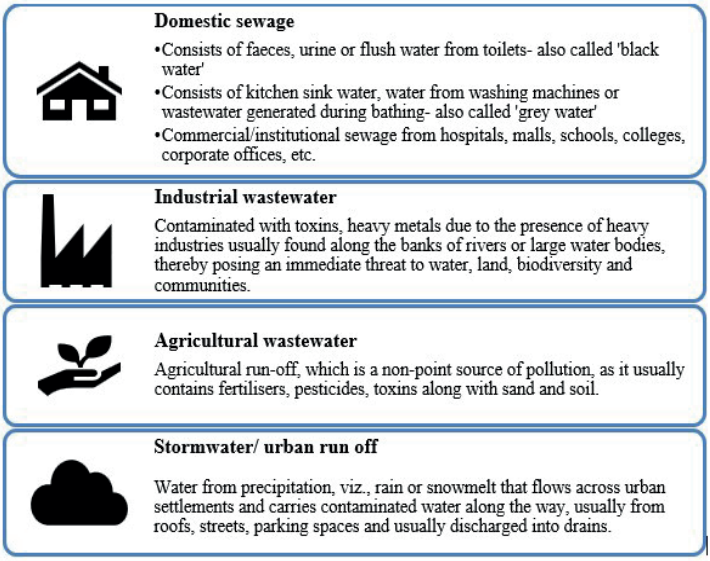
Wastewater is a combination of two words, waste and water. A huge part of urban water management, wastewater is liquid wealth that largely goes unnoticed. Clean water is essential for life, but with the impacts of climate change that have largely snowballed, using this untapped resource could be a well-meaning trade-off. When wastewater is treated well, it ensures:

- Ensures protection of rivers and oceans.
- Improves health by preventing water-borne diseases.
- Provides more water for farming and industry.
- Can be a resource through recovery of minerals (e.g., providing energy or fertilizer).
- Create jobs in building and operating treatment systems.

Since wastewater is a huge resource, investing in wastewater treatment is a smart move for communities and countries that want to meet big sustainability targets like clean water, good health, jobs, and environmental protection.

1.1 Types of Wastewater

Going by the UN definition, there are different types of wastewater depending on their source:



1.2 Wastewater in urban water management

Wastewater and land management go hand in hand, as there is competition for resources in a fast-paced world, which is aspirational and is exposed to rapid levels of urbanisation amidst rising population. Large land use/land cover (LU/LC) changes occur as there is an impact on water resources, arising out of huge water demand, water supply, and generation of wastewater, which again is largely untreated, getting 'lost' in the process, thereby leading to water scarcity.

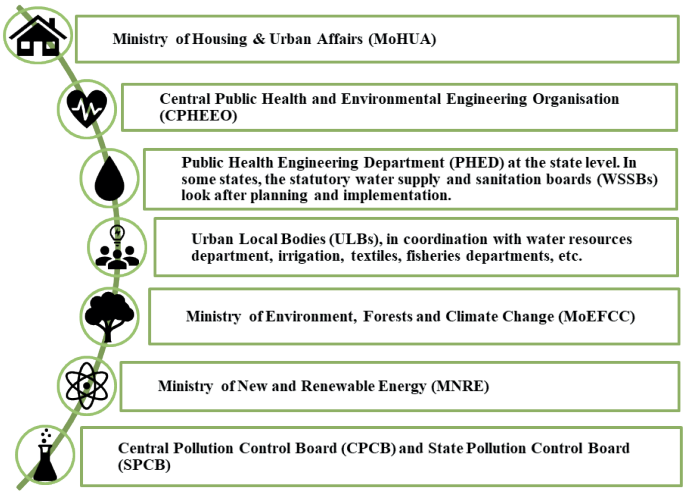
Wastewater management for every setting, be it rural or urban; coastal or riverine geography; or hill or plain topography, will be different with different cost analytics owing to ease, access, and logistics. Yet, after effective calculation and policy enumerations and keeping in mind the trade-offs, the best-suited methodology is to be adopted. This could be a mix of primitive, moderate, or advanced technology, keeping in mind the population, funding, and layout of a city.

Urban wastewater management in Guwahati or other NE Indian cities needs to be a part of policy discourse, understood as infrastructure upgradation with sanitation design that is robust, long-lasting, and replicable. Zoonotic diseases that are on the rise because of a warming climate have a bearing on

wastewater mismanagement. It is a crucial cornerstone in urban governance, and Guwahati is yet to experience the usefulness of having sewage treatment plants (STPs). For that to happen, an urgent focus is needed to have a sewerage network in place that will further improve drainage mechanisms.

1.3 Types of Stakeholders

The National Framework on the Safe Reuse of Treated Water, 2021, recommends the need for "widespread and safe reuse of treated used water in India that reduces the pressure on scarce freshwater resources, reduces pollution of the environment and risks to public health and achieves socio-economic benefits by adopting a sustainable circular approach.'' As water is a state subject, every state has its own rules and regulations and policies to implement, operate, and supply water and wastewater reuse. There is a coordination between the relevant departments and specialised agencies with municipal corporations, municipal councils, and notified towns at the local levels. Some of the major stakeholders are-



Additionally,

- The National Water Quality Monitoring Programme (NWQMP) of India, through its network of SPCBs, advises central and state governments on prevention, control, abatement of water pollution and sets standards on water quality in streams and wells.

- The National River Conservation Directorate (NRCD) implements the National River Conservation Plan (NRCP) and the National Plan for Conservation of Aquatic Ecosystems (NPCA) for conservation of rivers, lakes and wetlands in the country.

1.4 Challenges of managing wastewater

With increasing water demand throughout the globe, there will be gaps in the demand and supply of water. One of the best ways to reduce this gap will be to manage wastewater or rather fill in the gap by making provisions for supplying treated wastewater. This in turn will ensure the *circularity of water*. Some of the challenges to wastewater management broadly include: institutional, economic, technological, regulatory and social.

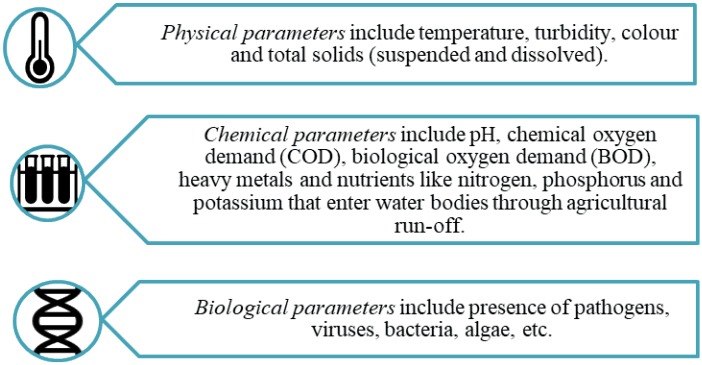
1.5 Circularity and sustainability of wastewater management

Liquid and solid waste management go hand in hand. For this to happen, sanitary landfills, STPs, FSTPs have to function in tandem. This demands sustained efforts towards treating effluents from industries at source, thereby reducing the nutrient load in large water bodies, which receive point and non-point sources of discharge that affects aquatic life at large. Linearity will lead to pollution of all sorts, but it is the circularity of water, waste and wastewater that acts as trade-offs, thereby reducing the effects of pollution at large. Therefore, it acts as an important pillar of circular bioeconomy, giving fresh perspectives to concepts of 'refuse, reuse or recycle'. Key examples of wastewater management that could ensure circularity and sustainability:

- Decentralised approach wherein small, medium and large industries have their own effluent treatment plants and large commercial and institutional spaces have their STPs.
- Nature based solutions (Nbs) that can be used in lake and wetland rejuvenation.
- Reuse of greywater in gardens and parks.
- Reuse of treated wastewater to irrigate farmlands or to give life to urban manmade forests.
- Bio-remediation methods to treat oil spills in water bodies that pose immediate threat to aquatic, bird and human life.

1.6 Role of Water Quality Assessment

Water quality assessment is extremely crucial in understanding pollution levels and the overall health of any water body. Standards of discharge or emissions are to be maintained as per government regulations. Water quality parameters include:



1.7 Where do Sustainable Development Goals (SDGs) stand in wastewater management?

Out of the 17 SDGs, SDG6 is specifically for water, i.e., 'water and sanitation for all'. The 'Water for People' website comprehensively lays out the eight targets under SDG6. Out of these eight targets, target 6.3 and 6A specifically mentions about wastewater, i.e.,

Target 6.3

By 2030, improve water quality and minimise release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally.

Target 6.A

By 2030, expand international cooperation and capacity-building support to developing countries in water and sanitation-related activities and programmes, including water harvesting, desalination, water efficiency, wastewater treatment, recycling and reuse technologies.

Water is a cross-cutting issue in all the SDGs. SDG-14, which is 'life below water' is again directly linked to SDG-6.

2. Best Practices on Wastewater Management from Indian Cities

2.1 Wastewater management in Delhi

Delhi is one of the most densely populated cities of the world with a population of more than 23 million as per world population review. The Delhi Jal Board (DJB) is primarily responsible for managing wastewater treatment plants and collecting, treating and disposing of domestic sewage. More importantly, under the DJB, the management of *Asia's largest STP* takes place, viz., the Okhla STP. The city generates 792 MGD (million gallons per day) of sewage or wastewater, which is treated at STPs installed in 21 locations with a total capacity of 667 MGD. Of the total sewage generated, about 72% (566.9 MGD) is treated and utilisation of STPs (i.e., actual treatment as against installed capacity) is about 84.9%. The remaining untreated sewage flows into the Yamuna River. Of the total sewage treated, around 89 MGD is used for irrigation, horticulture, construction and cooling of power plants. (Aijaz R, 2024)

Primary, secondary and tertiary methods of wastewater treatment are used, ensuring water quality standards are met before getting supplied. Breaking down every method of wastewater treatment is beyond the scope of this chapter.

Delhi mostly relies on ioT-based systems that offer real-time data monitoring alongwith SCADA (Supervisory control and data acquisition) technology. Activated sludge process combined with nature-based solutions (NbS) through constructed wetlands in different parts of the city are also considered. In unauthorised colonies and JJ (Jhuggi-Jhopdi) clusters, decentralised STPs are deployed.

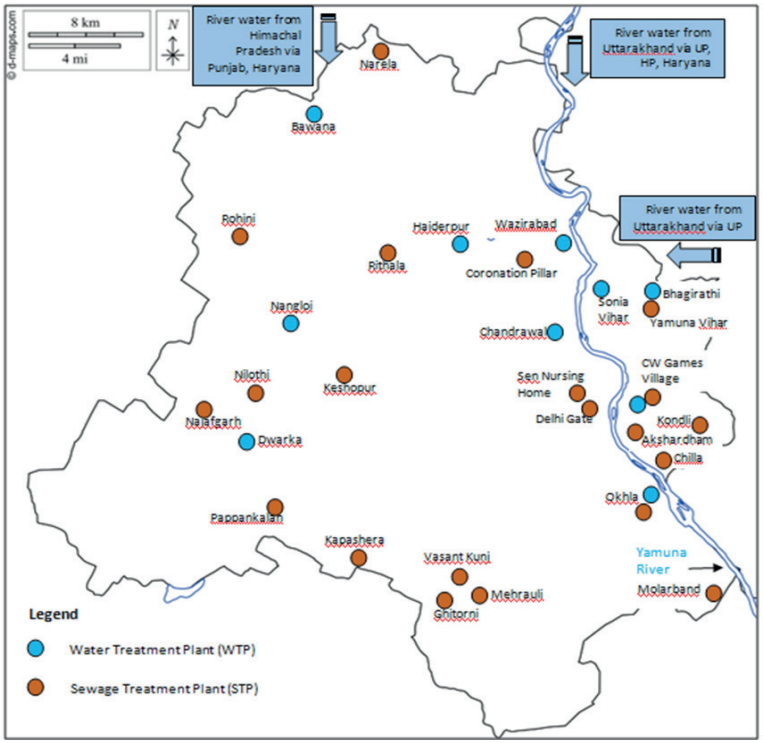


Figure 1: Water and sewage treatment plants in Delhi. (Source: Water and sewage quality in Delhi: Persistent challenges and ways. Observer Research Foundation.)

2.2 Wastewater management in Bengaluru

Bengaluru has about 14 million people, making it one of the fastest growing cities in India. The Bangalore Water Supply and Sewerage Board (BWSSB) is responsible for managing the city's wastewater. It is always in the news for acute water crisis, yet Bengaluru has been managing her water woes innovatively and comprehensively, thereby emerging as a leader in wastewater reuse. It is also interesting to note that Bengaluru has the highest number of decentralised STPs in the world, with over 2644 DSTPs in its kitty. (Hari Prasad, et al, 2024)

According to a report by WELL Labs, out of 1940 MLD of wastewater produced daily in the city, 640 MLD can be treated in decentralised STPs. It is estimated that apartments alone have the capacity to treat up to 500 MLD, which could potentially

take care of 25% of the city's sewage. Furthermore, as per a new mandate by the Karnataka government, residential complexes in the city can now sell a maximum of 50% of treated water collected from their STPs.

Primary, secondary and tertiary methods of treatment are used in Bengaluru, very similar to Delhi, with a focus on resource recovery. Sequencing Batch Reactor (SBR) is one of the technologies of prime importance in the city, especially used in apartment-level STPs. (Hari Prasad, et al, 2024)

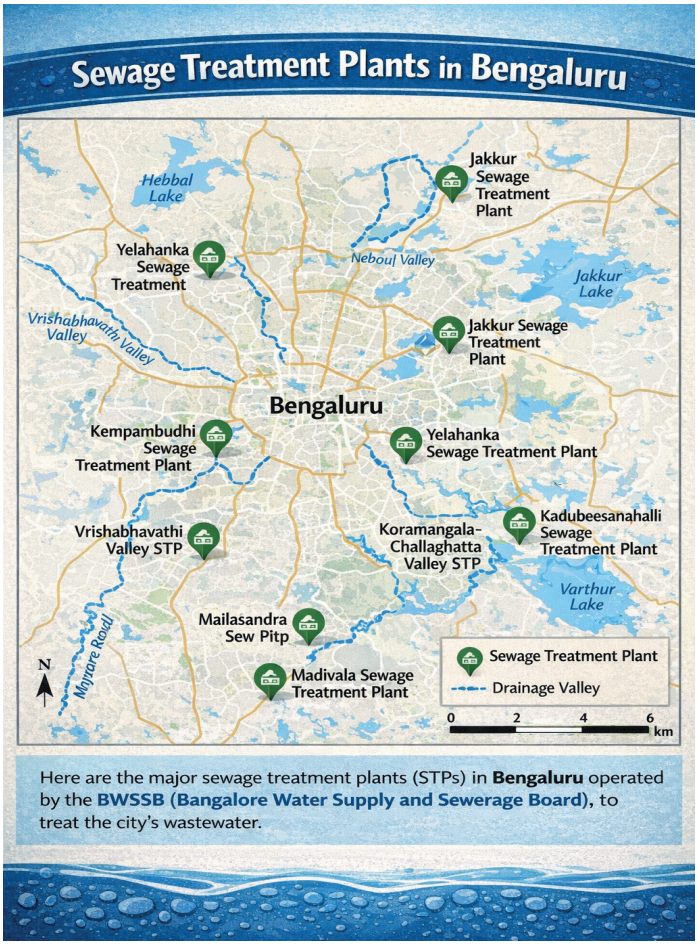


Figure 2: STPs in Bengaluru city. (Image/map created using ChatGPT)

3. Use of Treated Wastewater in Agriculture

Agriculture is the largest user of water in India, thereby leading to water insecurity in water-scarce basins. Nutrient-rich treated wastewater, especially through municipal sewage can be cost-effective for precision irrigation, as such kinds of wastewater have nitrogen, phosphorus and potassium (NPK) in them. Municipal wastewater is of increasing interest within the water-energy-food (WEF) nexus, given it allows the recovery of all three resources—water, energy and nutrients for crop production. It also provides wastewater treatment with an additional value proposition aside from the protection of our aquatic environment (Derschel, Qadir and Wilchelns, 2015). Wastewater and nutrient management are thus unmissable for climate action.

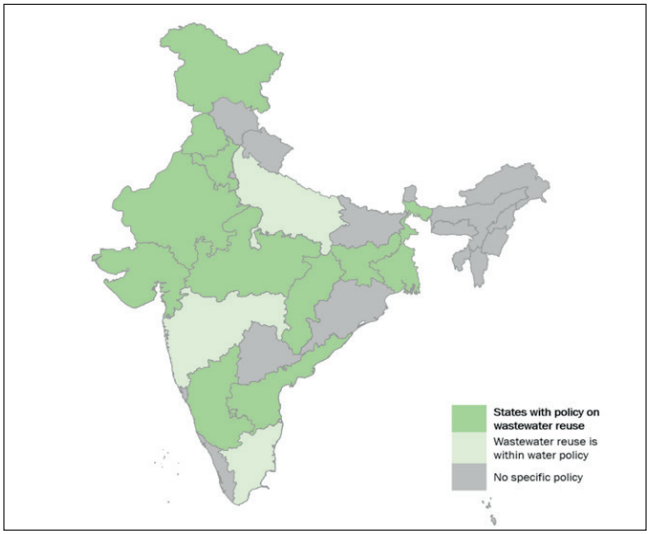


Figure 3: States having policy on reuse of treated water (Source: NITI Aayog report on 'Reuse of treated wastewater in urban/peri-urban agriculture in India').

NITI Aayog came up with a report titled 'Reuse of treated wastewater in urban/peri-urban agriculture in India' in June 2023. A crisp and concise report, it talks about water availability, demand, wastewater generation, examples of treated wastewater reuse in agriculture and the policies, strategies and regulations that lie therein.

4. Revisiting the Master Plan 2045 for Guwahati

The Kamrup Metropolitan District under Guwahati Municipal Corporation has 60 wards. In 2024, the Guwahati Metropolitan Development Authority (GMDA) released the draft GIS-based master plan 2045, which is futuristic just like any other Indian metropolitan city plan. These city plans are prepared keeping in mind the growth of urban areas for a period of thirty years. The scope of wastewater as a resource has been undervalued so far but is likely to change now with major infrastructural upgrades. Guwahati has been seeing exponential growth in every space and sector, and to not have STPs, sanitary landfills, or a mechanism to treat industrial pollutants is a recipe for disaster. As per the draft master plan, one of the primary goals is- 'to develop well-distributed social and physical infrastructure.' It aims to provide water supply and sewerage connection to 100% of households. A solid waste management system is to be provided for all kinds of waste.

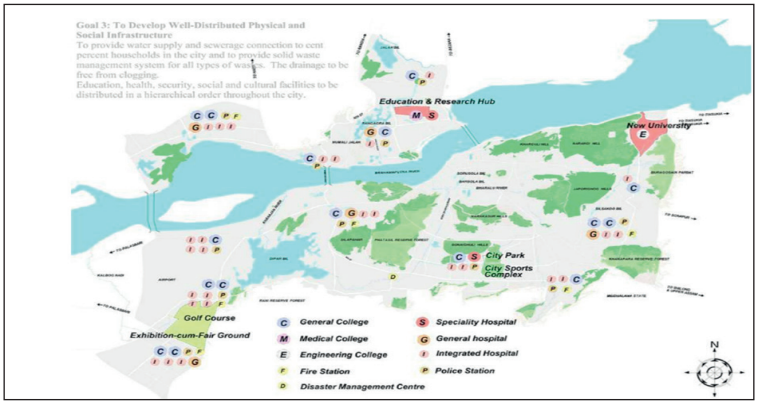


Figure 4: Map showing how the well-developed physical and social infrastructure in Guwahati city would be. (Source: Guwahati Master Plan 2025)

The water supply to the city is provided by three agencies, viz., Assam Urban Water Supply and Sewerage Board (AUWSSB), GMC and PHED through their existing system. Besides Railways, Indian Oil and defence agencies also have their independent supply systems for their areas. In the future, two other stakeholders have been considered, viz., GMDA and Guwahati Metropolitan Water Supply and Sewerage Board. Water is an important component for running macro

industries. Currently, Noonmati's IOCL refinery, railways, airport and defence establishments are collecting and treating their water requirement without depending on municipal water supplies, with their main source of raw water being from the Brahmaputra. The plan proposes that in the future, all major industries will arrange their water needs depending on their special requirement. The treatment and disposal of wastewater is also to be undertaken by these agencies.

Currently, the Guwahati Metropolitan Area (GMA) does not have any integrated sewerage system. Having septic tanks alone is not enough. Untreated effluent is released into the nearby drains and low-lying areas, causing high levels of pollution.

Heavy nutrient loading in river channels makes drains and rivers dead by destroying aquatic life. They also pose a major health risk during urban flash floods, which has become quite the norm in Guwahati. Having a well-laid-out sewerage system with STPs and FSTPs in sight is the need of the hour to ensure ecological flows (e-flows) in the Basistha-Bahini-Bharalu (BBB) system. Only then can the Brahmaputra remain less polluted. As per the city plan report, Guwahati has no mechanism to treat its industrial waste. In the case of septic tanks, the soak pits are becoming non-functional in many areas because of the high subsoil water table within a short span of time. The projected per capita wastewater generation was to be 80% of the water supply as of 2025.

Table 1: Water Demand in GMA-2025 (Source: Guwahati Master Plan 2025)

Zones	Planning Unit	Wards Covered	Projected Population	Gross Water Demand (in MLD)
North Guwahati	9	69, 70, 71	147,809	38
South Guwahati West	5, 6, 7, 8	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13 (Part), 65, 66, 67, 68	582,749	107
South Guwahati Central	1, 2, 3, 5, 10	13 (Part), 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 41, 42, 43, 44, 45 (Part), 47 (Part), 48 (Part), 49, 50 (Part), 51 (Part), 57 (Part), 59, 60	1,007,236	192
South Guwahati East	2, 3, 4, 10	40, 45 (Part), 46, 47 (Part), 48 (Part), 50 (Part), 51 (Part), 52, 53, 54, 55, 56, 57 (Part), 58, 61, 62, 63, 64	442,489	88

Table 2: Wastewater Load in Guwahati Metropolitan Area (GMA) (Source: Guwahati Master Plan 2025)

Planning Unit	Wards Covered	Projected Population (Year – 2025)	Generated wastewater in MLD (Year 2025)
1	18,19,20,21,23,25,26 27,28,29,30,31, 32,33 & 34	165076	23.77
2	15,16,17,22,24,55,56,57,58,59 & 60	401156	57.77
3	51,52,53,54 & 64	174627	25.14
4	46,61,62 & 63	59131	8.51
5	10,12,13 & 65	113409	16.33
6	3,4,5,6,7,8 & 9	93527	13.46
7	1 & 2	85087	12.26
8	66,67 & 68	230694	33.22
9	69,70 & 71	156124	22.48
10	11,14,35,36,37,38,39,40,41,42,43,44,4547,48,49,50	295071	42.49
	Total	**1773902**	**255.42**

For large and medium-sized industries located within Guwahati Metropolitan Area, it is proposed that they have their own effluent treatment plants while industrial estates should have Central Effluent Treatment Plant (CETP) to meet the standard for discharge of treated industrial effluents. Whereas small industries with very little pollution load can discharge their effluents after some primary treatment into municipal sewerage networks. The proposed STPs are to be located in three service sectors, the details of which are given in the table and map below.

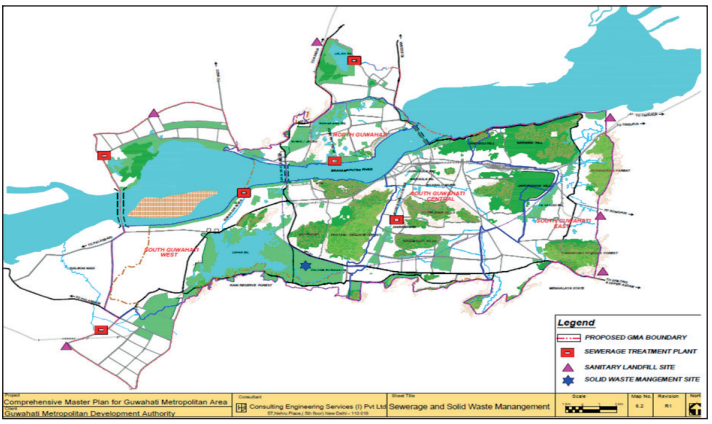


Figure 5: Map showing proposed sites of STPs in Guwahati city (Source: Guwahati Master Plan 2025)

Table 3: Proposed Location of STP with Location by 2025 (Source: Guwahati Master Plan 2025)

Sl. No.	Service Sector	Planning Unit	Location	Capacity in MLD (area in ha)
1	Eastern Service Sector	1,2,3,4 & 10	At Dhirenpara area	157.68 (20.60 ha)
2	Western Service Sector	5,6,7 & 8	On the Bank of Khanajan River	75.27 (8.66 ha)
3	North Service Sector	9	Near Confluence of Ghorajan River	22.5 (3.07 ha)
Total				**255.5**

Also, as per the master plan, the **activated sludge system** has been found to be the most suitable for treatment of sewage at different STPs.

5. Where does Guwahati stand in urban wastewater management?

As per the website of Guwahati Metropolitan Drinking Water and Sewerage Board, JICA is the largest bilateral donor for India. Since Guwahati does not yet have an engineered sewerage system, the urgency of the implementation of the scientific system of sewerage networks is palpable. Guwahati has a population of 1.2 million as per the world population review. This JICA-assisted sewerage project will serve as a crucial component of urban wastewater management. As per a feasibility report for sewerage schemes targeted at conserving the Bharalu River and prepared jointly by the Louis Berger Group, Inc. and DHI (India) Water and Environment Private Limited, the sewerage system for Guwahati has to be designed for the peak flow for 2050.

Table 4: Components of sewerage network of Guwahati (Source: Feasibility report for sewerage schemes)

SN	Main Components	Sub Components
1	Collection and conveyance system	Trunk, main, branch/lateral sewer line, manhole chambers, vent shaft, etc.
2	Sewage pumping stations	Terminal sewage pumping stations and lift stations, wet well, drywell, pumps, motors, rising main and accessories, electrical transformer and substation
3	Sewage treatment plants	Screen chambers, distribution chambers, grit chambers, chlorination tanks, gas holders, facultative aerated lagoons and sludge drying bed, electrical transformer and substation
4	Treated sewage disposal	Sump and pump house, pumps and fixture, gravity/forced main
5	Site development and building infrastructure	Site grading, roads boundary wall, administration building and essential staff quarters and area lighting
6	Laboratory	Lab building and testing equipment as prescribed in PHE manuals.

Untreated or semi-treated sewage is disposed of into the storm drains due to a lack of proper sewerage and wastewater drainage in the city. With a combination of decentralised STPs and a proposed centralised STP of 187 MLD capacity, Guwahati is yet to experience the service of treated wastewater reuse.

However, in 2025, as per the official website of GMDA, a pilot project for rejuvenating the Borsola beel was carried out by setting up an up-flow anaerobic sludge blanket-based STP. This was done by intercepting the drainage system flowing through the 8 municipal wards (18, 30-36) to the water body.

In some residential spaces, hospitals, hotels, and malls, decentralised STPs (DEWATS) are available, but it is not clear as to how many of these DEWATS are functioning properly or the kind of technology used to treat the wastewater generated. As per an official notification by National Mission for Clean Ganga (NMCG), 32 faecal sludge treatment plants (FSTPs) have been proposed for Assam. Mostly commissioned in 2024, there are functioning FSTPs in different urban local bodies across the state. The Centre for Science and Environment (CSE), as of 2026, carried out monitoring in seven FSTPs, viz., Mariani, Golaghat, North Lakhimpur, Tinsukia, Guwahati, Goalpara and Kokrajhar. It was reported that treated water from these FSTPs was deployed in gardening. Guwahati has one FSTP at Boragaon which has been operational since 2024 and the geotube treatment technology is used. (Arvind Senger and Rajarshi Banerjee et al. 2025)

6. Conclusion and way forward

The absence of a cohesive wastewater management framework with scattered data on wastewater generated (and treated) from various institutions makes it difficult to understand water accountability in Guwahati. Therefore, institutional reforms are a must for better water management at a time when water security issues are so glaring. Keeping in mind the circular water economy, wastewater management is a crucial component of the vision document of Viksit Bharat 2047. Therefore, in an era of water bankruptcy, it should be seen as a post-crisis response so that the pressure on existing freshwater resources is reduced. If and when Guwahati's urban wastewater management is looked into seriously, only then can it be replicated in other cities like

Dibrugarh, Silchar, Jorhat, Tezpur, etc. Wastewater has a huge market potential that can change how we think of water as a resource and economic good.

Having basic infrastructure like STPs is a good start, which has been delayed all these years, but once functional, many of Guwahati's sanitation woes can be solved in a changing climate. Systems thinking is the way forward that will make urban water governance efficient and pave a way for water accounting and auditing in the future.

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Majuli in Transition: Ecosystems, Communities and Policy Responses

20

Tracing Policy Influence on Majuli's Housing: A Timeline Study of Sustainable Incentives in Permanent and Impermanent Housing

Shubhangi Sharma*[1], Jambavati Gouda[2]

ABSTRACT

This study analyses the evolution of housing in Majuli, Assam, where flood-prone conditions historically fostered bamboo stilt houses known as chang ghar. The recent government policies, including the Pradhan Mantri Awaas Yojana - Gramin (PMAY-G), Aponar Apon Ghar, the Rural Housing Interest Subsidy Scheme (RHISS), and the Bamboo and Cane Policy, have prioritised pucca housing; thereby reshaping material choices and built forms. Using a qualitative, timeline-based analysis of literature and policy documents, the study finds that state-led incentives have accelerated a transition from traditional flood-adaptive bamboo houses to hybrid and fully permanent structures. While these policies have improved structural durability and access to amenities, they have simultaneously reduced the use of renewable materials and weakened embedded cultural practices.

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Hybrid typologies have emerged as adaptive compromises, reflecting community negotiation between policy compliance and traditional knowledge. The findings highlight the need for policy frameworks that integrate resilience, ecological sustainability, and cultural continuity rather than privileging structural permanence alone.

Keywords: *Majuli, Chang Ghar, Housing Policy, Climate Resilience, Sustainable Development, Indigenous Building Practices*

1 Introduction

Majuli, the world's largest inhabited river island, faces severe flooding, erosion, and riverine instability. These conditions shaped the Mising community's *chang ghars* as adaptive, elevated bamboo structures. However, modern policy interventions are reshaping these traditional forms (Khan et al. 2025; Singh 2014).

1.1 Environmental Context

Majuli's location in the Brahmaputra River makes it highly flood-prone. Annual inundations threaten settlements, agricultural lands and traditional housing, particularly the bamboo-based *chang ghars*. Indigenous construction methods with locally sourced materials like bamboo were historically tailored to these environmental challenges, allowing structures to survive floods with minimal repair. The elevated stilt design also provides effective cross-ventilation during the intense summer heat, ensuring thermal comfort without mechanical systems, an advantage that modern concrete construction often fails to replicate.

1.2 Socio-Cultural Context

Chang ghars incorporate communal knowledge of materials, spatial organisation and adaptive strategies. Modern housing practices, including hybrid or *pucca* constructions, alter these cultural norms (Times of India, 2024). Traditional chang ghars are more than shelters; they reflect the social and cultural rhythms of Mising life. The space beneath the raised platform accommodates livestock such as cattle, pigs and poultry, integrating animal husbandry into the household. The communal veranda, or *merboh*, serves as a shared space for weaving, craft-making and social interaction, while adjoining structures support extended family living and resource sharing. The shift

to enclosed concrete houses has disrupted these arrangements, reducing opportunities for livestock integration, community interaction and intergenerational knowledge transfer.

1.3 Policy Context

Various government policies provide incentives for durable, resilient and sustainable housing. Key policies include:

- PMAY-G – financial support for rural housing, primarily *pucca* homes.
- *Aponar Apon Ghar* – interest subsidies and financial aid to encourage sustainable construction.
- Bamboo & Cane Policy – promotes the use of treated bamboo and cane for resilient housing.
- RHISS (Rural Housing Interest Subsidy Scheme) – interest subsidy for rural housing loans.
- Assam Integrated Clean Energy Policy – clean energy integration into housing.
- Disaster Management Programs – reconstruction grants and embankment-based interventions.

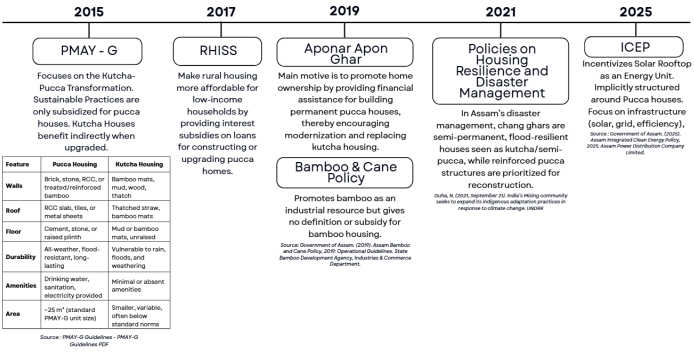


Figure 1: Timeline of Existing Policies and their relation to Impermanent and Permanent housing.

These policies shape material choices, housing typology and community adaptation strategies in flood-prone regions like Majuli District (District Disaster Management Authority Majuli 2023; Press Information Bureau 2023).

1.4 Key Definitions

1.4.1 Sustainable Incentives

Sustainable incentives are policy-driven measures, financial, material or regulatory, that encourage the adoption of housing practices aligned with long-term ecological and social sustainability. These may include financial subsidies (such as interest subvention under PMAY-G or RHISS), material support (e.g., bamboo treatment facilities under the Bamboo and Cane Policy), or amenity-based provisions (like solar energy integration under the Assam Integrated Clean Energy Policy).

1.4.2 Impermanent Housing (*Kutcha* Housing)

Impermanent or *kutcha* housing refers to structures built with locally available, renewable and perishable materials such as bamboo, cane, thatch or mud. In Majuli, the *chang ghar* is the most prominent example, elevated on stilts to withstand seasonal flooding.

1.4.3 Permanent Housing (Pucca Housing)

Permanent or *pucca* housing refers to structures built with durable, industrially produced materials such as reinforced cement concrete (RCC), fired bricks or stone. These are often promoted in government schemes like PMAY-G, where eligibility for subsidies depends on adopting such materials.

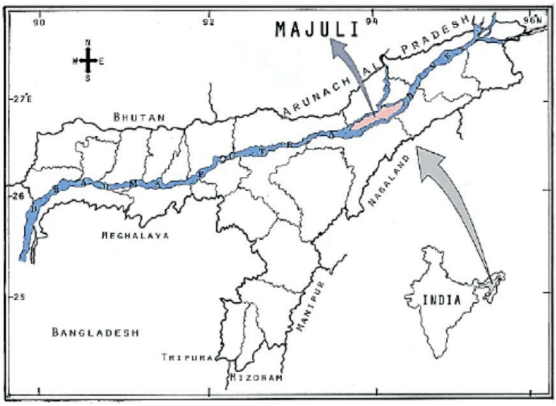


Figure 1(a): Location map of Majuli riverine island, Brahmaputra River, Assam, India.

Source: Adapted from Das et al. (2015)

2. Literature Review

2.1 Impact and Development Studies on Rural Housing and Policy, Assam/Majuli

2.1.1 Environmental Context and Flood Vulnerability

Majuli Island, in the Brahmaputra River, is one of the largest river islands in the world and highly dynamic due to river hydrodynamics and sedimentation patterns (Singh 2014). The island experiences recurring annual floods, typically between June and September each year, along with severe erosion and land loss, directly threatening housing structures. Studies highlight that traditional housing, particularly stilted *chang ghars*, evolved as adaptive responses to these stresses. *Chang ghars*, built from bamboo, wood and reeds, are elevated to accommodate seasonal flooding, provide natural ventilation and allow damaged components to be replaced with minimal resources (Goel 2024). Census data further confirm the predominance of bamboo-based housing in Majuli, accounting for over 80% of recorded houses (Census of India 2011). However, while ecologically attuned and culturally significant, modern policy-driven constructions, incentivized through schemes like PMAY-G, prioritise permanent concrete or brick houses, which can reduce adaptive flexibility in volatile environmental conditions (Barua 2023).

2.1.2 Socio-Economic Differentiation and Housing Choices

Wealthier households increasingly build entirely concrete *pucca* homes, which serve both as status symbols and to comply with subsidy criteria under government schemes (Chetia 2013). Middle-income families frequently adopt hybrid approaches, combining concrete foundations with bamboo walls or elevated bamboo superstructures, maintaining some degree of cultural continuity while accessing subsidies. Conversely, economically disadvantaged households continue to rely on traditional *chang ghars*, which, despite their environmental and cultural advantages, often do not meet formal "*pucca*" definitions required to access policy incentives.

2.1.3 Policy Implementation and Disaster Management

Policies such as PMAY-G, Rehabilitation Grants (RG) and state-level disaster management programs are designed to provide

resilience and secure housing for flood-affected communities (Guha 2021; Press Information Bureau 2023). Top-down approaches often fail to account for localized knowledge and environmental conditions, leaving certain households without support. Disaster management strategies frequently emphasize permanent structures that can withstand floods and erosion, but do not always integrate traditional stilted designs, reducing the adaptive capacity embedded in indigenous knowledge (National Institute of Disaster Management 2013).

2.1.4 Indigenous Knowledge and Cultural Preservation

Chang ghars are not merely structural solutions but represent the Mising community's accumulated knowledge of riverine ecosystems, seasonal floods and local materials (Goel 2024; Guha 2021). The literature emphasizes the need for policy frameworks that preserve adaptive traditional practices while introducing sustainable incentives for structural durability, highlighting a critical tension between modernisation and cultural resilience (Barua 2023).

2.1.5 Gaps in Development Studies

Although numerous studies document environmental vulnerabilities and socio-economic dynamics of housing in Majuli, gaps remain. Few studies systematically link policy interventions to material choices, cultural retention and long-term environmental sustainability.

2.2 Policy and Program Details Related to Bamboo Housing and Rural Development

2.2.1 Government Housing Programs and Financial Incentives

Government schemes such as PMAY-G, *Aponar Apon Ghar* and Rural Housing Interest Subsidy Scheme (RHISS) provide direct financial incentives to households for building resilient and climate-adaptive housing (Bhandari and SEEDS India 2022). According to the NABARD Potential Linked Credit Plan (2023–24), 589 houses were sanctioned under PMAY-G in Majuli district. PMAY-G emphasizes transitioning from vulnerable *kutcha* structures to semi-permanent or permanent *pucca* houses, sometimes including hybrid adaptations such as bamboo superstructures on concrete plinths. *Aponar Apon Ghar* similarly provides subsidies for constructing flood-resilient houses while

encouraging indigenous design features. RHISS offers interest subsidies on loans for rural housing, indirectly promoting sustainable building choices by reducing financial constraints.

2.2.2 Material and Design Incentives

Policy documents and studies on bamboo and cane-based housing highlight targeted incentives for locally sourced and sustainable materials (Choudhury and Chettry 2023; Hazarika and Baruah 2022). SEEDS India, for instance, introduced raised concrete stilts combined with bamboo walls to enhance flood resilience while retaining cultural relevance. PMAY-G hybrid guidelines encourage elevated plinths, treated bamboo and hybrid roofing systems to improve durability and reduce flood damage.

2.2.3 Policy Constraints and Integration Challenges

Despite clear incentives for sustainable housing, policies often impose constraints that limit flexibility. Definitions of *pucca* houses under PMAY-G and *Aponar Apon Ghar* prioritise concrete and brick structures, inadvertently devaluing traditional bamboo stilt houses (BNSK Bharat 2021). Limitations in material support, eligibility criteria and technical guidance can prevent households from fully leveraging their traditional knowledge, even when financial incentives are available. Literature highlights this tension, suggesting that while policies aim to promote resilience, they may unintentionally discourage ecologically sustainable practices and reduce cultural continuity (Hazarika and Baruah 2022; Ji and Punekar 2021).

2.2.4 Sustainability Outcomes and Future Directions

While financial and material subsidies have improved the flood resilience of selected households, the long-term environmental benefits remain uncertain. Current literature identifies the need for systematic monitoring and longitudinal research to assess the combined effects of policy, material innovation and traditional knowledge on housing sustainability in Majuli (Bhandari and SEEDS India 2022; Choudhury and Chettry 2023).

2.3 Objectives

The study explores the role of sustainable incentives in shaping housing practices, focusing on how financial, material and policy-driven encouragement have influenced the adoption

of durable and resilient construction materials. It examines the effectiveness of subsidies, clean energy provisions and material support in guiding households toward incorporating flood-resistant and ecologically sensitive solutions, while also highlighting the limitations of existing frameworks in promoting the continued use of traditional, renewable materials such as bamboo.

3. Methodology

This study employs a qualitative, timeline-based research methodology to investigate how government policies with sustainability incentives have influenced housing forms in Majuli, Assam. The methodology is structured into six distinct phases, each with specific objectives, methods, and expected outcomes (Figure 2).

3.1 Phase 1: Policy Collection and Timeline Development

The first phase involved collecting all relevant national and state-level housing policies applicable to Majuli, Assam, focusing on definitions and criteria for *pucca* and *kutcha* houses. Financial, material and amenity-based incentives tied to specific housing types were identified and a chronological timeline of key policy milestones was developed.

3.2 Phase 2: Literature Review of Housing Typologies

In the second phase, academic papers, reports and field studies on traditional stilt houses (*chang ghars*) and permanent houses promoted under PMAY and other schemes were reviewed. Material use, design features, and flood adaptation strategies were extracted and the transformations from traditional to hybrid to *pucca* typologies were summarized.

3.3 Phase 3: Establishing Criteria for Built Form

The third phase focused on analyzing policy documents to establish clear criteria differentiating *pucca* and *kutcha* houses. These definitions were then aligned with observed housing typologies in Majuli to create a consistent classification framework.

3.4 Phase 4: Linking Policy to Housing Transformations

Phase four involved mapping the introduction and updates of relevant policies against observed transformations in housing

types. Key shifts from traditional bamboo stilt houses to permanent *pucca* structures were highlighted, with attention to the impact of sustainability incentives on both permanent and impermanent housing. Cultural and traditional elements that were retained, adapted, or lost during this transformation were documented.

3.5 Phase 5: Assessment of Sustainability Potential

In the fifth phase, policies were reviewed for explicit mentions of eco-friendly or locally available materials and limitations imposed by the current definitions of *pucca* houses on sustainable practices were analysed. Traditional sustainable practices, including bamboo stilts and elevated plinths, were compared with modern *pucca* standards.

3.6 Phase 6: Synthesis and Interpretation

The final phase synthesized the entire timeline of policy influence on Assam's housing forms, highlighting current material practices in *pucca* houses and discussing how specific policy milestones shaped the built environment and material choices.

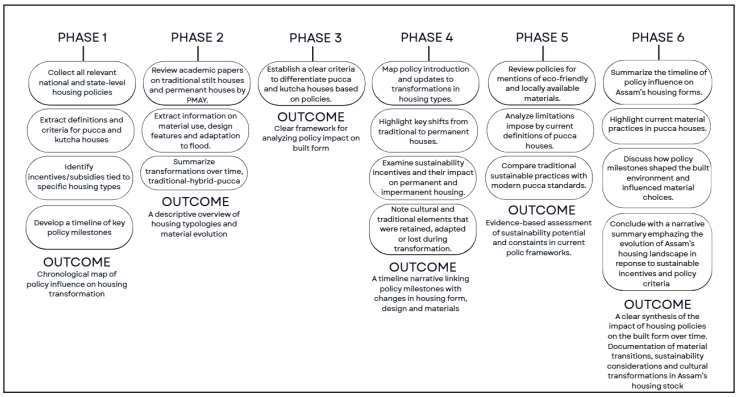


Figure 2: Diagram showing phase-wise methodology with sub-steps for the research conducted.

4. Results

The results of this study are organised as a timeline of housing evolution in Majuli, demonstrating how policy interventions, combined with socio-economic and environmental factors,

influenced the built form. The results highlight material transitions, cultural adaptations, and both positive and negative impacts of policy implementation on housing resilience and environmental performance.

4.1 Baseline Housing Composition (Census 2011 and Recent PMAY Data)

Census 2011 housing data for Majuli Sub-District recorded 54,892 houses, of which 44,903 (81.8%) were constructed using grass, thatch or bamboo as primary wall material. In contrast, 5,398 houses (9.8%) used burnt brick and only 102 houses (0.18%) used concrete. These figures provide a baseline of Majuli's housing composition prior to the large-scale implementation of PMAY-G and related schemes. Subsequent data illustrate a marked trend: NABARD Potential Linked Credit Plan records indicate that housing sanctioned under PMAY-G in Majuli district rose from a negligible number before 2015 to 589 houses in 2023–24 alone, reflecting an accelerating policy-driven shift toward permanent construction. While granular annual disaggregated data for Majuli remain limited in the published literature, the trajectory points clearly to a sustained expansion of pucca housing since the mid-2010s.

4.2 Stage 1: Traditional *Chang Ghars* (Pre-2010)

Before formal government housing schemes, the Mising community in Majuli relied on traditional bamboo stilt houses, elevated above flood levels and constructed with locally sourced bamboo, reed and wooden planks. The stilt system allowed water to flow beneath during floods, minimizing damage and enabling quick recovery, while thatched roofs provided natural ventilation and lightweight load-bearing properties.

4.3 Stage 2: Early Hybrid Interventions (2010–2014)

The first phase of policy-influenced transformation in Majuli's housing began with NGOs and small-scale interventions aimed at increasing structural resilience while maintaining traditional forms. The Sustainable Environment and Ecological Development Society (SEEDS) India introduced concrete bases for bamboo stilts, stabilising houses during floods, while bamboo walls and thatched roofs remained largely unchanged. SEEDS India's flood-resilient housing programme in Assam directly benefitted an estimated 150–200 households in and around

Majuli during this period (Bhandari and SEEDS India 2022). The intervention demonstrated that hybrid structural upgrades could significantly reduce flood damage without entirely displacing traditional materials or spatial configurations, establishing a model that later informed state-level policy guidelines.

4.4 Stage 3: Hybrid Structures (2015–2018)

As PMAY-G pilot schemes and *Aponar Apon Ghar* gained traction, households began constructing hybrid structures combining traditional bamboo walls with cement columns, wooden floors and CGI sheet roofs, reflecting policy compliance and practical adaptation. Impacts were mixed: structural durability and flood resilience improved, but traditional ecological practices eroded and material sustainability declined due to cement and steel reliance. PMAY-G progress reports for Assam indicate that approximately 1,200 rural households were supported statewide during the pilot phase between 2015 and 2018, with Majuli representing a priority district given its acute flood vulnerability (Press Information Bureau 2023). In these hybrid configurations, residents retained bamboo infill walls as culturally familiar elements while meeting the structural requirements stipulated by subsidy guidelines.

4.5 Stage 4: *Pucca*-form *Chang Ghars* (~2019–2021)

The full-scale rollout of PMAY-G and *Aponar Apon Ghar* policies led to permanent *pucca*-style *chang ghars*, typically around 25 square meters, constructed with RCC columns, brick or un-mortared masonry walls, cement screed floors and CGI sheet roofs, replacing traditional bamboo walls. Cultural adaptations were minimal; traditional spatial organisation was largely abandoned, stilts mostly removed and only elevated floors were retained for flood mitigation. NABARD district-level data indicate that Majuli recorded a substantial uptake of PMAY-G funding during 2019–2021, with beneficiaries primarily constructing this pucca-form typology (NABARD 2023–24). Impacts were mixed: structural safety improved, subsidy compliance was achieved and amenities such as toilets, cooking gas connections and electricity were integrated, but cultural authenticity declined, bamboo use dropped sharply, and ecological resilience was partially reduced as the capacity for rapid post-flood repair diminished.

4.6 Stage 5: Raised Plinth *Pucca* Houses (~2022–Present)

The most policy-influenced housing typology in Majuli consists of fully *pucca* houses with raised plinths of ~1.2 meters and shallow strip footings, reflecting policies emphasizing permanent, flood-resilient construction. Traditional bamboo construction is nearly absent, with only elevation and flood mitigation retained. Impacts are mixed: structural durability, policy compliance and access to amenities have improved, but traditional knowledge, renewable material use, cultural practices and ecological sustainability have declined. The cumulative transformation of *chang ghars* across these stages is illustrated in Figure 3.

4.7 Housing Typology Transformations



Figure 3: Evolution of Chang Ghar in Majuli, Assam, resulting in variations.

Table 1 synthesizes the relationship between housing form, policy influence, sustainability incentives and observed impacts across the five stages.

Table 1: Linking Housing Form to Policy and Sustainability Incentives with its Impact.

Stage	Housing Form	Policy Influence	Sustainability Incentive	Impact
1	Traditional *Chang Ghar*	Pre-2010, pre-policy	N/A	High resilience, fully adaptive to floods, culturally rooted
2	Hybrid *Chang Ghar* with concrete stilts (SEEDS)	Bamboo and Cane Policy, NGO support	Material support (cement + treated bamboo)	Improved stability, partial retention of cultural elements

3	Hybrid: Bamboo walls + wooden floors + concrete columns	PMAY-G (early pilots)	Financial support + material incentives	Balances traditional design with structural durability
4	*Chang Ghar* form, but mostly concrete	PMAY-G, *Aponar Apon Ghar*	Subsidy for *pucca* construction	Flood protection improved, but there was a loss of bamboo craftsmanship
5	Fully *Pucca* House (RCC + CGI + brick walls)	PMAY-G, RHISS, Assam Clean Energy Policy	Financial subsidy, clean energy add-ons	Modern durability, high cost and reduced cultural identity

4.8 Insights from Timeline Analysis

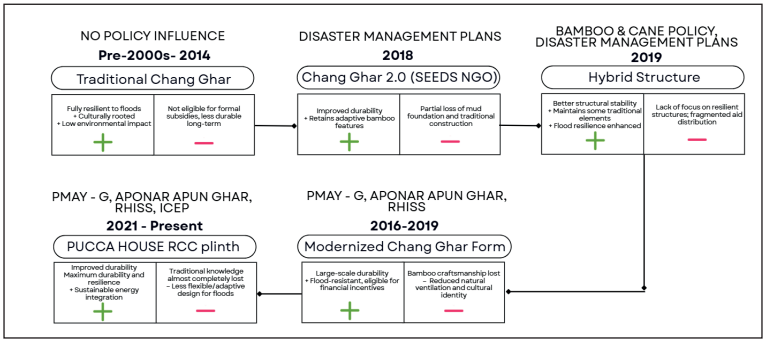


Figure 4: Timeline Analysis of Sustainable Incentives in permanent and impermanent housing.

Figure 4 presents the timeline analysis, linking policy milestones with material and typological transitions. Government policies have accelerated material transitions in Majuli, prioritising concrete and brick over bamboo.

5. Discussion

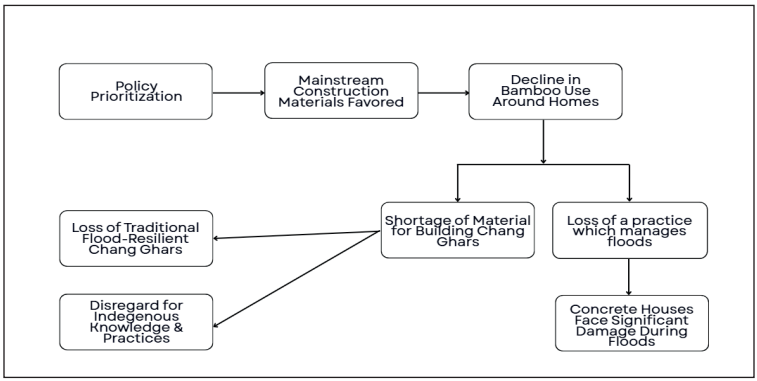


Figure 5: Flowchart diagram showing the impact of policy prioritisation on housing in Majuli. Source: Adapted from Goel (2024)

The evolution of housing in Majuli reflects the interplay of policy interventions, material adaptation and cultural practices. While incentives improved flood resilience and energy efficiency, *pucca* definitions marginalised bamboo solutions, limiting ecological sustainability.

Table 2: Linking Built Form Transformation to Policy Milestones from Timeline Analysis. Source: Author (2025)

Policy	Stage Impacted	Observed Change
Bamboo and Cane Development Programs	Stage 2	Introduction of treated bamboo, early hybrid foundations
PMAY-G Pilot	Stage 3	Hybrid structures with concrete columns, bamboo walls retained
Aponar Apon Ghar	Stage 4	*Pucca*-style *chang ghar* with brick walls, CGI roofs and an elevated plinth
RHISS	Stage 5	Raised plinth *pucca* houses, reinforced foundations, policy-driven durability
Clean Energy Initiatives	Stage 5	Inclusion of solar/energy-efficient systems

6. Conclusion

The five-stage trajectory examined in this study demonstrates that policy interventions in Majuli have profoundly reshaped housing typologies over roughly three decades. Community responses to these policies have not been passive. Ethnographic accounts and field observations documented in the reviewed literature indicate that households have actively negotiated the terms of policy compliance, selectively retaining elements of traditional design, such as elevated platforms, bamboo infill panels and communal verandas, within the constraints imposed by subsidy eligibility criteria. This adaptive negotiation reflects a form of vernacular agency that policy frameworks have only partially recognised. Understanding how communities in Majuli continue to adapt and respond to housing incentives is critical to forecasting future trends: if hybrid typologies are formally incentivised, demand for bamboo-integrated construction could stabilise or even grow, reversing the current decline in traditional material use.

6.1 Summary of Key Findings

This research analysed housing evolution in Majuli, focusing on *kutcha* and *pucca* structures under government policies and sustainability incentives. Policies like PMAY-G, *Aponar Apon Ghar*, RHISS, the Bamboo and Cane Development Policy and Clean Energy Incentives transformed traditional bamboo stilt houses into hybrid and fully *pucca* forms. Emphasizing structural durability and subsidy compliance, they promoted concrete foundations, brick walls, CGI roofs and raised plinths, often reducing ecological sustainability. Policies improved structural safety and flood resilience but reduced ecological sustainability and cultural diversity.

6.2 Contributions of the Study

This study maps policy influence on the transition from traditional *kutcha* to *pucca* housing in Majuli, showing how incentives and material provisions shape household choices and typologies.

6.3 Policy Implications

Policies should reward the use of bamboo and other renewable materials, and hybrid housing forms should be eligible for

subsidies to bridge traditional knowledge with modern requirements. Cultural preservation is crucial, encouraging stilted foundations, ventilation strategies and spatial configurations, while integrating cultural assessments into policies.

6.4 Limitations and Future Research

Primarily, reliance solely on secondary data prevents direct verification of household responses, construction practices and local perceptions. The long-term ecological and social impacts of material transitions could not be empirically measured, limiting the assessment of sustainability outcomes. Household surveys and interviews could validate secondary findings, providing insights into community perceptions of hybrid and *pucca* houses, barriers to adoption and cultural acceptance. Simultaneously, quantifying the carbon footprint, energy use and ecological impact of bamboo versus cement- and brick-based houses would help evaluate the long-term sustainability of hybrid typologies.

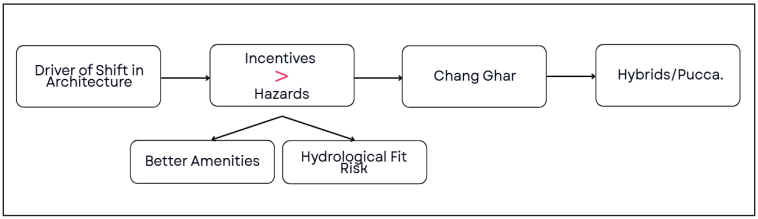


Figure 6: Flowchart diagram showing the conclusion and its effects.

6.5 Final Conclusion

The findings indicate that policy interventions have strongly shaped material and structural decisions, encouraging households to adopt permanent construction while marginalising certain sustainable and traditional practices. As illustrated in Figure 6, incentives have acted as primary drivers of architectural change. At the same time, cultural knowledge embedded in traditional stilt houses has been partially lost, underscoring the importance of culturally sensitive policy frameworks.

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21

Exploring Traditional Coping Strategies in Regions with Perennial Floods: A Study of Majuli Riverine Island

Ritam Talukdar[1]

ABSTRACT

Natural disasters like floods are a recurrent phenomenon in the Brahmaputra floodplains. The once seasonal floods have become increasingly difficult to predict as rainfall patterns change due to climate change. This exacerbates the flood-induced challenges, particularly for those residing in remote regions, underscoring the need for adaptive measures. This study, conducted in Majuli Island, a highly flood-prone area, aims to probe into the realm of traditional knowledge as an alternative coping mechanism. Empirical evidence was collected using purposive sampling in six satras. Data was collected using unstructured interview schedules, scratch notes, field notes, and field diaries. Thematic analysis was used to identify recurring themes and patterns related to traditional coping strategies. The study elucidates how indigenous practices and cultural traditions serve as effective mechanisms for coping with recurrent natural disasters, particularly floods.

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Through an examination of housing structures, agricultural practices, medicinal plants used, and cultural festivals, the research reveals the intricate interplay between different traditional strategies.

Keywords: *Traditional Knowledge, Coping Strategies, Floods, Majuli*

1. Introduction

Natural disasters like floods have long affected human societies, with recent years seeing frequent events such as wildfires, cyclones, and floods. Despite modern scientific interventions, many mitigation measures, particularly in India, have failed (Watwani, 2020). Traditional knowledge, now recognized as complementary to experimental science, offers valuable insights for disaster prevention, preparedness, and response in sustainable, community-based ways (Jha & Jha, 2011).

Majuli, one of the world's largest riverine islands, lies within the Brahmaputra floodplains at an elevation of 60–85 meters (Saharia et al., 2013). Its rich blend of Vaishnavite and indigenous traditions faces threats from recurring floods and erosion, leading to loss of livelihoods, displacement of *Satras*, and cultural decline. The state's inadequate response has deepened vulnerability among Majuli's 160,000 residents (Baruah, 2023), who continue to rely on traditional coping methods (Baruah, 2023).

1.1 Understanding Traditional Knowledge

Traditional knowledge, also termed local, folk, or indigenous knowledge, refers to community-based understandings passed down through generations. It differs from Western scientific knowledge, being local, culture-specific, orally transmitted, and rooted in survival and adaptation. Despite its informal nature, it remains vital for managing environmental risks. Indigenous knowledge and scientific knowledge should be viewed as complementary, each offering insights into coping with change and gathering hazard-related information (Mavhura et al., 2013).

1.2 Global Indigenous Communities and Natural Calamity Resilience

Globally, indigenous communities have demonstrated remarkable resilience through long-developed ecological

knowledge and practices. Berkes (2009) documents how communities maintain livelihoods and traditions amid environmental shifts using adaptive land management and community-based governance. The Inuit, for instance, interpret sea ice and climate patterns to anticipate flooding. Turner et al. (2000) similarly highlight indigenous adaptability against pressures such as industrialization and globalization, stressing context-specific resilience strategies.

1.3 Indigenous Resilience in India

In India, indigenous groups like the Gond, Santhal, Bhil, and Mishing display deep-rooted resilience against floods through Traditional Ecological Knowledge (TEK) passed orally across generations. The Mishing of Assam, for instance, construct stilt houses or *chang ghars* designed to endure Brahmaputra floods (Tamuli, 2021).

Communities in Rajasthan have developed the *Khadin* rainwater harvesting system—earthen embankments that capture monsoon runoff for dry-season farming and agroforestry practices integrating trees with crops for soil fertility and fuelwood (Goyal et al., 2018). Such practices sustain livelihoods and biodiversity under extreme drought and irregular rainfall.

Many indigenous groups now blend TEK with technology, using mobile communication, satellite imaging, and community-based early warning systems to manage flood risks more efficiently (Hiwasaki et al., 2014). This hybrid approach strengthens both traditional and modern resilience capacities.

1.4 Indigenous Resilience with Special Emphasis on Floods

Indigenous communities worldwide use generations of knowledge to endure floods and related disasters (Berkes, 2009). In Zimbabwe's Mazarabani region, Mavhura et al. (2013) document how traditional methods of prevention, adaptation, and distress mitigation such as protecting homes, livestock, and food stores remain highly effective despite intensifying floods.

Similarly, Jha and Jha (2011) found that the Lepcha community in Sikkim combines indigenous awareness of monsoon-related floods, landslides, and droughts with formal government efforts.

The Inuit of the Arctic employ deep environmental awareness to forecast floods caused by ice blockages and storm surges, constructing elevated shelters and moving provisions to high

ground (Dowsley et al., 2010). In the Mekong Delta, integrated farming systems that combine aquaculture, rice, and fruit cultivation allow sustainable production and food security amid seasonal floods (Bach et al., 2022).

In Southeast Asia, communities employ elevated houses and terraced paddies to mitigate flood impacts (Thomalla et al., 2006). In India, various indigenous flood management practices reflect this same resilience. Examples include raised housing structures , floating gardens (*phares*) made of water hyacinth that enable year-round cultivation (Al-Maruf, 2020), and natural flood prediction through animal behaviour and river observation.

Community-based governance further supports resilience by fostering collective decision-making, resource sharing, and solidarity during crises.

2. The Island

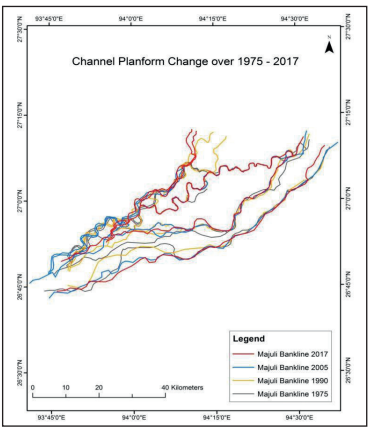
The Brahmaputra, spanning 580,000 km² across China, India, Bangladesh, and Bhutan, is one of the world's largest river systems. Originating from Tibet's Chema-Yung-Dung glacier, it flows 2,880 km before reaching the Bay of Bengal, sustaining life across Assam's floodplains.

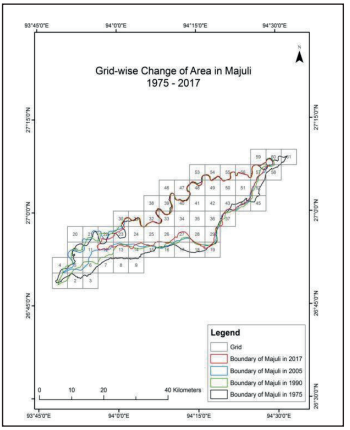
Majuli, the world's largest river island, lies within this basin. Once 1,255 km², it has shrunk to 422 km² due to severe erosion. Frequent flooding and erosion threaten its wetlands, livelihoods, and Vaishnavite *Satras* (India Today, 2016). Historically, communities coexisted with floods, but modern flood-control infrastructure disrupted this balance, intensifying disaster risks. Families in erosion-prone villages like Salmora face repeated displacement and economic distress.

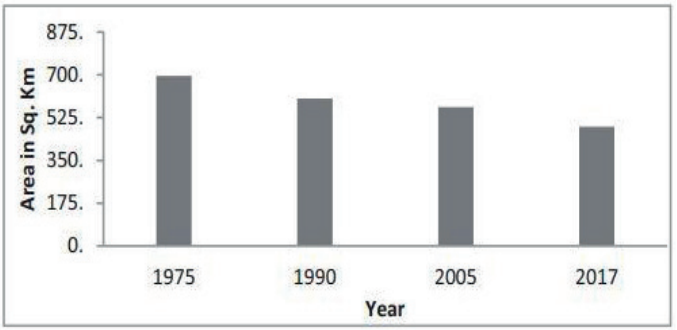
Assam's flood control measures date back to the Ahom period, but large-scale embankment construction expanded during colonial and postcolonial regimes (Guha, 1967). The Assam Embankment and Drainage Act (1953) led to nearly 5,000 km of embankments along the Brahmaputra. In Majuli, over 100 km of embankments built since the 1980s have worsened erosion, reshaping the island into a hazard-prone landscape.

Majuli's erosion and flooding have intensified over the past century. Earthquakes in 1897 and 1950 altered the Brahmaputra's course, increasing vulnerability. Roy, Pandey, and Rani (2020) documented erosion from 1975 to 2017 using LANDSAT data,

revealing a reduction from 629.2 km² to 487.5 km². The annual erosion rate rose from 1.75 km² per year (1975–1990) to 6.7 km² per year (2005–2017). The most severe erosion occurs at the Brahmaputra Subansiri confluence and the southern and southwestern zones of the island. Several grid areas (1–10, 17, 20, 21, 45, and 61) have been completely lost, illustrating the accelerating environmental crisis.







3. Research Methodology

Indigenous knowledge systems are vital for reducing disaster impacts and enhancing flood resilience (Muvhura et al. 2011). Traditional knowledge aids in identifying disaster causes, predicting events, and formulating effective mitigation measures (Jha & Jha, 2011). Majuli, regarded as Assam's cultural heritage (Roy et al., 2020), faces recurring floods and riverbank erosion despite modern interventions. Documenting the community's

long-standing coping mechanisms is essential. Integrating local and scientific knowledge can strengthen flood management and policy formulation.

The objective of this study was to document the traditional coping strategies employed by the people of Majuli to manage floods.

The study is set in Majuli district, Assam, and follows a qualitative, cross-sectional design using both primary and secondary data. Purposive sampling will focus on flood-prone Satras such as Notun Kamalabari, Auni Ati, Adi Alengi, Sakopara, and Garmur (Roy et al., 2020). Data was gathered through unstructured interviews, field notes, and diaries until saturation. Thematic coding was used to identify recurring patterns. Ethical protocols were maintained to ensure confidentiality and participant comfort.

6. Findings and Discussions

The local people, of whom the largest community is the Mising, possess generational knowledge preserved through folklore and festivities. Migrating from present-day Arunachal Pradesh during the reign of Ahom king Suhungmung (Dihingia Raja), they settled in Majuli for its fertile, flood-enriched soil and abundant fish. Over centuries, their agricultural and riverine lifestyle fostered deep expertise in flood-adaptation strategies. The succeeding sections discuss key elements of their flood-adaptation approach.

4.1 Housing Structure: Chang-Ghar

The *chang-ghar* (stilt house) has a long history in Assam, though its origin remains uncertain. It emerged in hilly and flood-prone regions to provide safety from water and animals. Elevated on bamboo or wooden stilts, it reflects both environmental adaptation and cultural expression. Traditionally, three main types existed: *Deka Chang*, *Gabhoru Chang*, and *Murung Ghar*.

The *Deka Chang* served as a communal dormitory for unmarried boys, fostering unity and imparting life skills such as tool use, construction, and cultural practices. Built east–west and often ornately crafted, it was a symbol of village pride. The *Gabhoru Chang* was its female counterpart, where girls learnt domestic and social responsibilities. The *Murung Ghar*, a community hall without walls, hosted gatherings, games, songs, and discussions

on collective issues. Of these, only the *Murung Ghar* persists today, albeit with reduced social importance due to nuclear family systems and formal education.

Most families now live in individual *Okums*, residential *chang-ghars* designed for functionality and environmental harmony. Their slatted bamboo floors allow easy disposal of waste and spillage, feeding livestock below and simplifying cleaning. The raised structure shelters animals and includes an extended platform (*jera*) used for drying food, basking, or as flood refuge.

Traditionally, the house consists of five structural layers each above and below the main frame that symbolically linked to human senses and believed to enhance hygiene. Built mainly from bamboo, wood, and rattan cane, the floor's crisscross design promotes airflow, keeping interiors cool in summer and warm in winter due to bamboo and hay insulation.

Cooking centres around the *meram*, a multifunctional hearth with layered storage: the *kida* stove, *perab* net for drying fish or paddy, *rabbong* shelf for warming rice beer (*apong*), and *kumbang* for storing grains. Modern storage alternatives, however, are replacing traditional systems.

An additional granary, the *bhoral*, is built similarly but sealed with mud and cow dung to prevent grain loss. Livestock shelters are also raised for protection during floods. Recent decades have seen material and conceptual shifts: metal sheets increasingly replace hay roofs for durability, and concrete stilts substitute bamboo due to longevity and cost efficiency. These adaptations reflect changing perceptions of permanence as families now view their houses as long-term assets tied to secure land rights. Rising bamboo prices have also led to modified construction, such as omitting some of the five traditional layers to reduce costs.

The *chang-ghar* thus embodies centuries of ecological wisdom and cultural continuity, adapting gradually to socio-economic change while retaining its essential resilience-oriented design.

4.2 Preparedness

Swimming is learnt naturally from a young age, integrated into daily life rather than formal training, fostering resilience and self-reliance. Children gain essential skills by assisting elders in fishing and other activities. Boats, traditionally crafted by men,

serve as primary flood preparedness tools. When materials are scarce due to logging restrictions or cost, makeshift rafts from banana trunks demonstrate the community's adaptability and proactive approach to navigating Majuli's flood-prone environment.

4.3 Prediction/Foretelling

Communities in flood-prone Majuli rely on environmental signs and traditional knowledge to predict floods, a practice rooted in necessity when modern technology was unavailable. Even today, limited infrastructure like electricity and internet makes traditional forecasting vital.

Animal behaviour is a key indicator: restlessness in livestock, barking dogs, wailing cows, ant migration, and unusual movements of birds, reptiles, and insects signal impending floods. Insects, living underground, sense rising water and move to higher ground, cues the community observes and interprets. Environmental cues such as prolonged rainfall, cloud patterns, soil moisture, and wind directions like North-to-South winds (*posua botah*) also guide predictions, often explained by interactions with nearby hills.

Transmission of this knowledge occurs orally, with women playing a central role. Folklore, folktales, and proverbs link flood predictions to animals and seasonal fruits, embedding experiential wisdom in cultural memory. Collective sharing ensures the community prepares for and mitigates flood impacts.

This integration of observation, cultural practices, and communal knowledge highlights the depth of indigenous understanding, demonstrating a sophisticated, context-specific system for anticipating natural disasters in Majuli.

4.4 Agriculture

Agriculture in Majuli demonstrates strong adaptation to the island's flood-prone geography and riverbank erosion. Rice varieties like *Bao* and *Ahu* are cultivated for their resilience to inundation. *Bao* thrives in waterlogged areas and is harvested after floods, while *Ahu* grows quickly, allowing harvest before floods, minimizing crop loss. *Ahu* also features in local festivals, reflecting its cultural significance.

Beyond rice, households maintain small plots for vegetables and medicinal plants, providing food security when markets

are inaccessible during floods. These practices highlight the community's strategic use of land for survival, not solely for livelihood.

However, recurrent flooding and riverbank erosion pose persistent challenges, causing soil loss, sand deposition, and reduction of arable land, disrupting traditional farming practices. Despite these pressures, the community's adaptive strategies like timely crop selection, small-scale vegetable plots, and flexible farming cycles demonstrate a deep understanding of local environmental dynamics and the use of traditional knowledge to sustain livelihoods and food security under challenging conditions.

4.5 Medicinal Plants

Geographical isolation, socio-economic constraints, and recurrent floods make healthcare access in Majuli challenging. Pharmacies are distant, government provisions limited, and incomes low, restricting access to modern medicine. Consequently, the community relies heavily on indigenous knowledge and medicinal plants for primary healthcare.

Table 1: Use of medicinal herbs

Local Name	Scientific Name	Use for	Methodology
Jilmill	Chenopodium	Stomach ache, diarrhoea	Leaves are boiled and consumed with water
Dimora Paat	Ficus racemosa	Piles and diarrhoea	Leaves are boiled and consumed with water
Mani-muni	Centella asiatica	Dysentery, Diarrhoea, digestion	Boil in water
Bhedailota	Paederia foetida	Dysentery	Boil in water
Tita phool	Phlogocanthus thyrsi	Cough, worms	Eat raw, as a tea or vegetable
Bhilongoni	Macrothelypteris 2quati	For mothers after giving birth	Cook with some dish

Xewali Paat (leaves)	Nyctanthes arbor-tristis	Immunity	5-6 leaves, mashed in water, consumed after separating the water
Xewali Phool (flower)	Nyctanthes arbor-tristis	Cough, malaria	Swallowing
Lai Jabori	Drymaria cordata	Pneumonia	Remove the roots, take about 100g of it and grind it, boil it, let it dry and make balls
Daederia Xak		Antiseptic for cuts	Grind it and apply the paste
Kola Haladi	Curcuma caesia	Pain, stomach ache, cough	Dry it and eat
Jaluk	Piper nigram	Indigestion, body ache, pneumonia	The fruit is crushed and consumed
Bon jaluk	Paederia foetida	Jaundice	The plant is cooked

Traditional flora is used strategically to address prevalent post-flood health issues. Gastrointestinal disorders like dysentery and diarrhoea are treated with plants such as *Jhilmil*, *Manimuni*, and *Bhedailota*, with knowledge passed intergenerationally, especially from mothers to children. Damp conditions promote respiratory ailments, mitigated using *Kola haladi* and *Tita phool*. Water contamination increases risks of malaria, jaundice, and pneumonia, for which plants like *Jaluk, Bon jaluk, Xewali Phool,* and *Lai jabori* are utilized.

This knowledge is embedded in folklore, rituals, and daily practices, demonstrating a sophisticated, context-specific healthcare system. The community's reliance on medicinal plants highlights both the adaptive capacity and resilience of traditional knowledge in responding to environmental and health challenges in flood-prone areas.

4.6 *Mibu* (Traditional Head Priest)

The *Mibu*, a traditional head priest and healer, historically held immense significance, believed to connect with gods and foresee the future. They administered rituals, prayers, and healing during hardships or festivals. Becoming a *Mibu* required divine dreams, sharp memory, and a sense of communal duty. Today, few remain, and modern education and technology have reduced their numbers, causing a loss of traditional knowledge.

4.7 Festivals

The festivals of Bihu and *Ali-Ai-Ligang* are central to agriculture and cultural preservation in Majuli, marking the start of the agricultural season and reinforcing the community's bond with nature. *Ali-Ai-Ligang*, celebrated in spring, involves sowing *Ahu dhan* seeds and performing rituals like *Juri* to seek blessings from ancestors for a successful harvest. Offerings include rice beer, seeds, and lamps, traditionally performed by a *Mibu* but now often led by the head of the family.

Families pray for protection from pests, storms, and other calamities, with excess harvest shared with the needy. The festival also includes *Gumrag*, a vibrant performance of singing, dancing, and playing instruments like the *dhol*, believed to rejuvenate the earth and attract divine favour. These rituals and performances transmit agricultural knowledge, cultural practices, and community values across generations.

Bihu similarly celebrates agricultural cycles and fosters social cohesion through communal feasts, dances, and rituals. Both festivals highlight the intimate connection between culture, agriculture, and nature while reinforcing collective responsibility, inclusivity, and resilience. They ensure the continuity of traditional practices, strengthen social bonds, and preserve the community's identity amidst changing times.

7. Conclusion

The Majuli case study highlights the resilience of traditional knowledge in coping with floods, erosion, and limited infrastructure. From flood-adapted housing and agriculture to medicinal plants, *Mibus*, and festivals, these practices ensure survival and social cohesion. Preserving and integrating them with modern systems is vital for sustainable, culturally rooted disaster management.

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The Impact of Climate Change on Aquatic Insect Diversity with Special Reference to Majuli, Northeast India

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ABSTRACT

The climate is an increasing global issue with extensive impacts on ecosystems, mostly on insect diversity and distribution. Insects play a vital role as pollinators, decomposers, and food sources for many organisms. Insects are found in a wide range of land habitats, water bodies, soil & underground, plants and trees, parasites, and homemade structures. Aquatic insects play a vital role in ecosystems. Climate change, rising temperatures and lower oxygen levels in water are causing aquatic insects to become smaller and experience increased mortality. Climate change negatively affects aquatic insects by disrupting life cycles and causing the loss of bioindicator species. These changes impact the entire ecosystem because aquatic insects are a vital part of both aquatic and terrestrial food webs. Among aquatic insect Texa, Ephemeroptera, Plecoptera & Tricoptera (EPT) are well-known bioindicators of environmental changes. Mayflies, stoneflies, and caddisflies are powerful tools for monitoring freshwater health and can provide a comprehensive view of how climate change is impacting aquatic ecosystems.

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Majuli, the largest river island in the world, provides every possibility for the aquatic insect fauna of the island. Altogether insects belong to six orders, and twenty families were recorded from Majuli during study periods. This chapter highlighted the effects of climate change on aquatic insect diversity in Majuli, Northeast India.

Keywords: *Climate Change, Aquatic Insects, Diversity, Majuli.*

1. Introduction

Aquatic ecosystems are highly diverse habitats that include ponds, lakes, streams, rivers, wetlands, reservoirs and ditches. Aquatic biodiversity is one of the most essential characteristics of aquatic ecosystems for maintaining stability and means of coping with any environmental change. Aquatic insects are indispensable within freshwater ecosystems, fulfilling diverse ecological roles and acting as reliable indicators of environmental health and water quality (Tamina S. et al. 2024). They are known to be associated with water for most of their life cycle, and thus, any change in their number and composition of population at a given time and space may indicate a change in water quality. Among aquatic insect texa, Ephemeroptera, Plecoptera & Trichoptera (EPT) are well-known bioindicators of environmental changes. Climate change, habitat alteration, pollution and invasive species pose significant threats to aquatic insect communities, highlighting the pressing need for further research to uncover their ecological resilience and vulnerability (*Borkataki, S*. et.al., 2021) . Live aquatic insects represent eleven insect orders. Among them, the larvae of species of moths (Lepidoptera), wasps (Hymenoptera), lacewings (Neuroptera), stoneflies (Plecoptera), alderflies (Megaloptera), dragonflies and damselflies (Odonata), flies (Diptera), and lacewings (Neuroptera) are aquatic with terrestrial adults. Aquatic bugs (Hemiptera) and beetles (Coleoptera) are entirely aquatic throughout their larval, nymphal, and adult phases (*Bharti, S.S. & Yeole S.M.*, 2025). The giant water bug (Hemiptera: Belostomatidae) is a top predator in wetland ecosystems, serving as biological indicators of the health of lentic ecosystems and as effective biological control agents for freshwater snails and mosquitoes.

Climate change can lead to biodiversity losses across different ecological scales and, in particular, drive shifts in species distribution ranges. In South Korea, giant water bugs used to be commonly found in shallow, small ponds near agricultural fields, but habitat loss due to urbanization and chemical pollution has led to a decline in their population sizes and distribution range (*Kim,Yi., S.,* et. al., 2024). Aquatic insects play an important part in the functioning of aquatic ecosystems. They are essential clusters of invertebrates in the aquatic ecology, where they influence food webs. They are the primary nutritive fauna of fish during the larval stage. Aquatic insects are frequently effective indicators since they may be found in practically any type of environment and many of them are habitat specialists (*Basumatary, M.D.,* 2023). One of the most important qualities of an aquatic ecosystem is its capacity to sustain its stability in terms of aquatic biodiversity. Aquatic insects are classified into the following taxonomic orders: ***a***. Collembola-springtails, ***b***. Ephemeroptera-mayflies, ***c***. Odonata—damselflies and dragonflies, ***d***. Plecoptera-stoneflies, ***e***. Hemiptera-true bugs, ***f.*** Neuroptera/Megaloptera-dobsonflies, ***g***. Trichoptera-caddisflies, ***h***. Lepidoptera—butterflies & moths, ***i.*** Coleoptera—beetles, ***j.*** Hymenoptera—diving beetles, ***k***. Diptera-mosquito larvae. These studies overlook of the use of aquatic and semi-aquatic insects as bioindicators, particularly climate change in Majuli, a northeastern region of India.

2. Materials and Methods

Study Area: Majuli is the world's largest river island in Assam, situated between 26°45′ N and 27°12′ N latitude and 93°39′ E to 94°35′ E longitudes. The island is about 300-400 km and is formed by the Brahmaputra River and a branch of the Brahmaputra, i.e., Kherkutia Huti, which is joined by the Subansiri River.

Collection of aquatic insects and identification: Aquatic insects were collected from five wetlands locally known as beels by using mosquito nets and traditional fishing gears, 75% ethanol, a P^H meter, plastic bags, and other necessary materials. Sampling occurred at 15 days intervals between 8.00 am to 11.00 am. local time and identified using standard key.

3. Results and Discussion

The aquatic insect comprises 43 species categorized under 6 orders and 20 families. The aquatic insects identified during study periods from Majuli are given below:

Table 1: Aquatic insects recorded from selected samplings sites during 2023-24

Sl. No.	Order	Family	Species	Availability
1.	Odonata	Libellulidae	*Brachythemis contaminata*	Odonata are most active and available during warm, sunny weather, peak populations generally occurring during the monsoon/ rainy season.
			Rhyothemis variegata	
			Crocothemis servilia servilia	
			Orthetrum pruinosum	
			Pantala flavescens	
			Aethriamanta brevipennis	
			Orthetrum sabina	
			Brachydiplax chalybea	
			Neurothemis fulvia	
			Diplocodes nebulosa	
			Acisoma panorpoides	

		Coenag-rionidae	*Ischnura aurora*	Odonata are most active and available during warm, sunny weather, peak populations generally occurring during the monsoon/ rainy season.
			Ischnura elegans	
			Ceriagrion coromandelianum	
			Ceriagrion calamineum	
			Agriocnemis pieris	
			Agriocnemis pygmaea	
			Aciarion hisopa	
2.	Coleo-ptera	Gyrinidae	*Dineutus sp.*	Coleopteran beetles are generally most available and active from spring through early autumn.
			Cybister fimbriolatus	
			Cybister sp.	
		Dysticidae	*Loccophilus sp.*	
			Hydaticus sp.	While activity is highest in summer, many species are active for over 6 months.
			Herophydrus musicus	
		Hydro-philidae	*Hydrophilus sp.*	
		Curculio-nidae	*Bagous sp.*	
		Carabidae	*Pterostichus sp.*	

3.	Hemiptera	Belostoma-tidae	*Diplonichus rusticus*	Hemip-teran insects (true bugs, aphids, leafh-oppers, white-flies etc.) are generally most abundant and active from spring through autumn.
			Diplonichus sp.	
			Lethocercus indicus	
			Lethocercus sp.	
		Nepidae	*Leccotrephes sp.*	
			Ranatra sp.	
		Gerridae	*Gerris sp.*	
		Notone-ctidae	*Enithares sp.*	
		Corixidae	*Micronecta sp.*	
4.	Epheme-roptera	Caenidae	*Caenis sp.*	Predom-inantly occurring from spring through autumn.
		Baetidae	*Baetis sp.*	
		Isony-chiidae	*Isonychia sp.*	
5.	Trichoptera	Glossoso-matidae	*Glossosoma sp.*	Generally peak during spring and summer.
		Hydropsy-chidae	*Diplectrona modesta*	
6.	Diptera	Simulidae	*Simulium sp.*	Highly seasonal. Peak during spring and summer.
		Chiron-omidae	*Chironomus sp.*	

Altogether 3145 numbers of aquatic insects distributed among 19 families belonging to 6 orders viz., Odonata(782), Coleoptera(745), Hemiptera (1267), Ephemeroptera(121), Trichoptera(87) and Diptera (143) were recorded. Odonata are most active and available during warm, sunny weather, peak populations generally occurring during the monsoon/rainy season. Coleopteran beetles are generally most available and active from spring through early autumn. Hemipteran insects (true bugs, aphids, leafhoppers, whiteflies etc.) are generally most abundant and active from spring through autumn. Ephemeropteran are predominantly occurring from spring through autumn. Tricopterans are generally peak during spring

and summer. Dipteran are highly seasonal. Peak during spring and summer. Hemipteran are one of the most dominant order during monsoon season and was found all the sampling sites. The highest mean population was recorded during monsoon (1570) followed by post-monsoon (1231), pre-monsoon (206) and lowest was recorded during winter (138) were recorded. Among the aquatic system , highest mean population was observed in open water areas completely devoid of vegetation followed by water bodies with dense, floating and submerged vegetation and lowest was observed in water near brick industry during winter.

3.1 Aquatic insects and climate change

Climate change significantly impacts insects by altering their geographic ranges, increasing metabolic rates, and shifting life cycle timing, often leading to rapid population declines or increased pest prevalence. Climate change, driven by global warming, significantly impacts insect populations, with studies indicating that up to 65% of species face extinction risks over the next century due to changing habitat conditions.

Climate change is a significant factor in the spread and assistance of establishing alien invasive species. Invasive species are non-native organisms that can cause harm to the environment, economy, or human health. They often outcompete native species and disrupt the balance of ecosystems they invade. For an alien insect to become invasive, they must arrive in that region, survive and reproduce. Human activities such as international trade, agriculture, and global trade have caused the exponential spread of species beyond their native regions. Climate change may have a positive or negative effect on the invasiveness of a species. Various climate factors such as temperature, wind, humidity, could control the dispersal of pests and insects to a new geographic area. The temperature rise contributes to the survival of insects where they could not survive earlier (Raza et.al., 2014). The fruit tree mealybug , *R.invadens*, is expanding its geographical range to new areas and climate change to increase the chances of its infestation (Azrag et. al. 2023).An increasing temperature speeds up the development and reproduction of insects, producing more generations annually and ultimately causing more crop damage.Climate change is directly linked to larger population densities, faster rates of development and more

frequent outbreaks of the green peach aphid (Bale and Hayward, 2010). The effect of temperature increase due to climate change brings about differences in factors such as availability of water, the incidence of strong winds, and the timing and intensity of sun (Rahman et.al.,2018). The rise in the temperatures cuts the generation period, resulting in higher generation in a year, and increases the quantity of brood, which may lead to a sudden increase in insect populations (Bentz et.al.2019). Insects that are restricted to certain areas due to low temperature may have the benefit of increasing their range of distribution (Roques et.al. 2014). Among the atmospheric changes of the last half century, the increase of CO_2 is one of the most important documented (Prentice et al. 2001). According to research, variations in CO_2 levels brought on by climate change mat affect insects in several ways, including population dynamics, behaviour, and interactions with the environment (Skendzic et al. 2021). Rising levels of CO_2 bring about more growth of plant vegetative parts, but at the same time it also increase the incidence of injury caused by many herbivorous insects (Nihal, 2020). An increase rate of parasitism was observed in another study, which was on examination of grain aphids fed by parasitoid wasps at an elevated CO_2 level, but the same effect of CO_2 level lower fertility of the wasps (Chen et al. 2007). Threats to insects include invasive species, pesticides use, and habitat degradation. These stressors and climate change may combine increasing susceptibility of insects populations to their impacts. Therefore to create efficient conservation plans and minimize the potential ecological effects of these changes, it is essential to comprehend the intricate relationships between changing CO_2 levels, insect populations, and climate change.

3.2 Discussion

The study revealed that the diversity of aquatic insects is abundant in the wetlands of Majuli. There are more than 140 wetlands locally known as *beels* and *dubies* in Majuli. These are a rich, diverse group of aquatic insects with immense ecological, floral, and faunal values. During study period 43 species belonging to 6 orders and 20 families were recorded. 48 species belonging to 6 orders and 20 families recorded during their study (Borkakati et al. 2018). A total of 30 aquatic insects belongs to 6 orders and 17 families were recorded from Joysagar tank, Sibasagar District, Assam (Gogoi, 2026). 12 species of aquatic insects belong to 4

orders and 8 families recorded from Dibru River near Dibru Saikhowa National Park (Guha et al., 2017). 23 species of aquatic insects belonging to 3 orders and a2 families were recorded from Keibul Lamjao National Park (Loktak Lake), Manipur (Gupta, 2015). 25 different species of aquatic insects belongs to 6 orders and 13 families were recorded from three permanent ponds of Guwahati, Assam (Hasan, 2016). 28 species belongs to 6 orders and 18 families were recorded from three permanent water ponds from Kaliobar Subdivision, Nagaon, Assam (Mahanta et al. 2018). Arthropods are sensitive bioindicators of environmental change, they strongly respond to changes in temperature and precipitation that alter abundance, distribution , and life cycles. Climate change affecting insects pests, natural enemies and pollinating species that are essential for agriculture (Rafiei, 2025). As insects are cold blooded animals, climate change impacts insects significantly, and displays various and complex effects on crop pests worldwide (Singh, 2023). The effect of long term , gradual warming on insects declines is not always immediately apparent. Discernible changes in insect population dynamics, their distribution, phenology or abundance are usually detected after critical performance thresholds affecting fecundity, survival and other vital rates surpassed (Harvey, 2022). Majuli wetlands recorded diverse group of aquatic insects so far but due to rapid urbanization and global climate change it is need of the hour to conserve them.

4. Conclusion

The climate change impacts aquatic insects in various ways, such as diversity and abundance of the insects, geographical distribution, introduction to alternative food plants, impact on the extinction of species, and changes in activity and relative abundance of natural enemies. Aquatic insects are the most widely used organisms in freshwater biomonitoring of human impacts and can provide reliable information on habitat and water quality. Aquatic insects are vital to freshwater ecosystems, acting as primary nutrient recyclers, food sources, and crucial bioindicators of water health. Majuli, the largest river island, has more than 140 wetlands (beels and dubies), which are the main habitat areas of these aquatic insects. The diverse, yet sensitive, wetland ecosystem of the Majuli is threatened by environmental and climate changes, making conservation of insects crucial for ecological balance.

Acknowledgements

The author would like to express his sincere thanks to the Department of Zoology, Majuli College, and the local fishermen and villagers of Majuli for their affection and encouragement during the course of study.

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23

Women as Vanguards of Environmental Protection and Climate Resilience: Evidence from the Mising Community of Majuli District

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ABSTRACT

Popularised in the early 1970s, the discourse on the protection of the environment, sustainable development, and climate change on Mother Earth is still a matter of concern for humanity. The awareness was raised by Rachael Carson's book 'Silent Spring' and the Stockholm Conference of 1972 and then followed by several conferences. As the first line of interaction with the ecosystem, women are always vital players in environmental conservation and sustainability. Several conventions, including the Beijing Platform for Action, have noted the role of women in sustainable development patterns and the need for participation in environmental decision-making. Women play multifaceted roles in society as farmers, forest product collectors and protectors, holders of traditional knowledge, and practitioners of climate resilience techniques. Proponents of eco-feminist theory shed light on these roles of women in environmental discourse, which is often overlooked by society.

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Majuli, being the largest river island located in the Brahmaputra River, faces ecological pressures like erosion, floods, changing landforms, etc. In these vulnerable conditions, the livelihood of the indigenous community of Majuli is intimately tied to nature. And women of these communities are central to the environment-livelihood nexus. Their expertise in traditional seed conservation, architecture, livelihoods, and agricultural practices provides a living example of the connection among women, the environment, and resilience. This paper focuses on climate-resilience techniques and traditional knowledge systems practiced by women in Mising communities in the Majuli district of Assam. It examines how these indigenous women contribute to environmental protection and adaptive resilience through their cultural and ecological practices.

Keywords: *Women, Climate Resilience, Indigenous Knowledge System, and Environment.*

1. Introduction

The recent trajectories shifted the world's focus from the political space to environmental protection. Climate change has shown worsening effects, which have forced the global community to unite and discuss these issues across different platforms. Women are the worst sufferers of environmental degradation, as the traditional sexual division of labour makes women more connected with nature. Gradually, many feminists started linking women and the environment, which led to the development of a new branch of study, i.e., ecofeminism. Bringing together feminism and environment, ecofeminism argues that the domination of women and degradation of the environment are consequences of patriarchy and capitalism. There are many conferences that emphasize the role of women in the protection of the environment. The Beijing Platform for Action noted the role of women in sustainable development patterns, and Agenda 21 also pointed out this. The Beijing Platform for Action also emphasized women's participation in environmental decision-making. It mentions 'gender mainstreaming,' which means making sure that the rights of both men and women are visible in all policies. With all these efforts, women's position in environmental protection has been highlighted and placed at the forefront of climate resilience. (Agarwal, 2009)

Majuli, the largest inhabited river island, is situated at the heart of the mighty Brahmaputra River. Majuli is a climate hotspot with issues like floods, riverbank erosion, and soil degradation. Women from different indigenous groups of Majuli are worse victims of these issues, as their whole livelihood is solely connected with the environment. They are cultivators, weavers, seed keepers, forest managers, and custodians of indigenous ecological knowledge. Placing women at the center of climate resilience, this chapter will highlight the major techniques of the Mising community of Majuli district. Their role in seed preservation and agro-diversity, water resource management, community forestry practices, architectural adaptation, etc. is best described as their role in climate resilience. Overall, this chapter will argue that women of these indigenous communities function as a vanguard of environmental protection and climate resilience through everyday practices, collective action, and cultural stewardship.

2. Theoretical Perspective on Women-Environment Linkage

Women—environment linkage has a broad theoretical framework under the concept of eco-feminism. Ecofeminist thinkers like Sherry B. Ortner, Susan Griffin, Vandana Shiva, Maria Mies, etc. drew the world community's focus towards the connection between women and the environment. Both women and nature share a subordinate and instrumental relationship to men and face the same attitude and pattern of male domination. Ecofeminism draws a parallel between environmental degradation and the oppression of women. As women are mostly confined to the private sphere, they are connected with nature for every work, and therefore, they are also the worst sufferers of environmental degradation (Buckingham, 2000). Sherry B. Ortner, in her book 'Is Female to Men as Nature is to Culture?', said nature is identified as having female attributes, and culture is masculinist. And women are subordinate to men, and in the same way, nature is subordinate to culture. She believed women's subordination is the result of the human mindset that human culture is superior to nature (Ortner, 1972).

Another renowned Indian feminist thinker, Vandana Shiva, views women as the primary protectors of biodiversity. In her article titled "Women's Indigenous Knowledge and Biodiversity

Conservation," Shiva argues that the marginalisation of women and the destruction of biodiversity go hand in hand. Diversity is central to women's traditional labour and epistemology. While modern science and technology often introduce monoculture into agricultural systems, women's indigenous knowledge preserves ecological diversity. For example, women's expertise has long been the mainstay of the indigenous dairy industry, and in forestry, their knowledge is vital for utilising biomass as feed and fertiliser. Women rely on renewable biological sources for feed, fertiliser, fuel, and fibre. Shiva contends that modern capitalist modes of production dismantle this indigenous knowledge system, which is inherently sustainable. She calls for a "revival of the other," drawing upon traditional philosophical concepts such as *shakti*, *prakriti*, *purusha-prakriti*, and *ardhanarishvara*. Shiva conceptualises these frameworks as the "feminine principle" and advocates for their active revival and application (Shiva, 1992).

International policy frameworks have increasingly echoed these perspectives. Adopted at the 1992 UN Conference on Environment and Development in Rio de Janeiro, Agenda 21 dedicated Chapter 24 to global action for women towards sustainable and equitable development. It urges governments to implement measures that enhance women's participation in decision-making, policy formulation, and programme management. Agenda 21 also emphasizes eradicating female illiteracy, alleviating women's domestic workloads to facilitate public participation, and strengthening non-governmental organisations and national machineries to support gender-responsive capacity building. Building on this momentum, the 1995 Beijing Declaration and Platform for Action underscored the necessity of integrating gender perspectives and granting women equal access to and full participation in power structures.

Subsequent international summits reinforced these priorities. The 2002 World Summit on Sustainable Development in Johannesburg reaffirmed the importance of gender mainstreaming in environmental governance. In 2004, the United Nations Environment Programme (UNEP) hosted the first Global Women's Assembly on Environment ("Women as the Voice for the Environment") in Nairobi, Kenya, firmly positioning women's concerns at the center of international

conservation efforts. Following this, UNEP adopted a formal decision in 2005 to mainstream gender perspectives into all environmental policies and programmes. More recently, during the 26th session of the Conference of the Parties (COP26), international delegates emphasized the necessity of expanding women's representation at the climate negotiations table, noting that while women are disproportionately impacted by environmental degradation, their leadership and insights remain critical to effective climate action. Significant progress has also occurred through institutional networking and high-profile recognition, exemplified by the awarding of the 2004 Nobel Peace Prize to Wangari Maathai, founder of the Green Belt Movement. Initiatives such as the Network of Women Ministers of the Environment, originally established with 22 female environment ministers and 28 women leaders of environmental NGOs, continue to highlight women's capacity to bring innovative perspectives and holistic solutions to global environmental policy (United Nations Division for the Advancement of Women [UNDAW], 2005).

3. Role of Women as Custodians of the Environment: A Case Study of the Mising Community of Majuli

Majuli, being the largest river island, has been a land defined by its unique ecosystem. Majuli's geographical identity is inseparable from the Brahmaputra River's dynamic river system, and climate change has increased the unpredictability of flood cycles and intensified livelihood risks. The lives of the indigenous communities of Majuli often go with the rhythm of water. Their livelihood process is connected to nature, and that has been central to their survival and to sustaining their practice in such an environment. Among all the communities, the Mising tribe is one of the major tribes of Majuli. They are characterised by unique ecological practices and cultural traditions. Women occupy a central position in Mising societies, as they are fully responsible for managing household granaries, weaving textiles, maintaining kitchen gardens, and assisting in agricultural operations. These roles defined women as the sole protectors of the environment and sustainable practices (Sinha & Doley, 2023).

Floods and erosion pose a serious threat to the island, and climate change makes this natural disaster even worse. The Mising community of Majuli adopts some resilience techniques with a deep understanding of nature. For instance, *Chang-ghar*, referred to as *Kare Okum* or *Taleng Okum* in the Mising language, is a traditional stilt house constructed as an adaptive resilience strategy against seasonal floods. Typically elevated 6–7 feet above the ground, it is built from local materials such as bamboo, thatch, and wood. The floor is made of split-bamboo slats that allow air to circulate freely, while the roof is thatched with reeds or palm leaves. Women play a vital role in organizing and maintaining these elevated domestic spaces, managing food security by safeguarding food grains and seeds during inundations, and caring for children, the elderly, and livestock. A *chang-ghar* typically features a multi-tiered hearth structure over the *meram* (the central fireplace used for daily cooking). Above the *meram* sit two tiers called *perab* and *rabbong*, which are used to smoke and store meat, fish, and clay pots of *apong* (traditional rice beer). Near the ceiling is an additional storage rack known as the *kumbang*, where vegetables and seed stocks are preserved. As flood levels rise and fall over time, the community can adjust the height of the platform, making these stilt houses an effective flood-adaptation mechanism (Guha, 2021).

Further, the livelihoods of the Mising community are agrarian, and farmers select crop varieties aligned with micro-climatic patterns. They cultivate short-duration *ahu* rice, *sali* rice, and particularly *bao* rice, a deepwater red-rice cultivar that is naturally resilient to submergence in flood-prone zones. Additionally, to ensure household food security during floods, they construct floating bamboo seedbeds to grow vegetables. Mising women play a primary role in preserving these seed stocks, storing them inside bamboo containers kept within the elevated *chang-ghar*. The seeds are preserved using smoke from the hearth, which protects them from insect pests and humidity for extended periods. This seed bank acts as a safety buffer, enabling rapid reseeding if standing crops are lost to floods. Women also cultivate home gardens on raised mounds near the house, preserving heirloom seeds of vegetables such as bottle gourd, ridge gourd, and pumpkin (Chutia, 2020).

Additionally, to cope with recurring disruptions, the Mising tribe has developed indigenous food preservation practices designed to guarantee food security during seasonal shortages and floods. Women utilize multiple preservation techniques, most notably smoking and fermentation. Small fish and meat are placed above the hearth on bamboo racks, where constant heat and smoke dehydrate them and prevent decay over long periods. Another prominent technique is the preparation of *namsing*, a traditional fermented fish product. Small fish (such as *mouwa* or *goroi*) are pounded with herbs and spices in a traditional foot-operated or hand-operated pounder (*dheki* / *hat-dheki*), packed tightly into hollow bamboo tubes, and cured near the hearth. This paste can last up to two years without spoiling (Baruah et al., 2021). Women also preserve bamboo shoots through fermentation, known as *iku*, where cleaned shoots are packed and sealed with banana leaves to allow anaerobic fermentation and prevent spoilage. Furthermore, they produce a traditional alkali (*kola khar*) from the filtered ash of burnt banana peels and leaves and rely on sun-drying for various vegetables and fish to inhibit bacterial growth. Through these community-held techniques, Mising women serve as the primary custodians of indigenous food resilience (Kumari et al., 2012).

Also, as noted by the United Nations International Strategy for Disaster Reduction (UNISDR, 2009), communities bolster their resilience by maximizing the use of localized knowledge and resources. Mising women draw upon experiential understanding to manage crises and support household safety. For mobility during floods, the community constructs dugout wooden watercraft known as *ollung*, as well as rafts assembled from buoyant banana pseudo-stems (*banana boats*) to transport goods and family members. Women's self-help groups (SHGs) contribute significantly to community-level disaster preparedness and relief coordination. Furthermore, community elders and women utilize meteorological folk indicators such as observing lunar halos, cloud formations, and animal behavior to anticipate flood surges and prepare emergency provisions in advance (Guha, 2021).

These are major forms of resilience techniques used by women of the Mising community. But several constraints limit them as the sole protectors of the environment and also limit their

ability to adapt their climate resilience techniques. Although the Mising society is much more egalitarian, it still has a patriarchal structure. That structure limits women's access to decision-making in the village council and to environmental governance and land-use strategies. This results in the underutilization of women's knowledge in climate governance. Customary inheritance laws reduce women's access to property, and that's why they have less authority to implement sustainable agricultural techniques. Educational and information barriers further restrict women from the effective implementation of climate resilience techniques. Government schemes and climate adaptation programs often fail to reach women effectively due to language barriers, bureaucratic hurdles, and a lack of gender-sensitive outreach. Economic marginalisation often made them dependent on their male counterparts, and that limits their ability to invest in climate resilience techniques. Strengthening their role requires gender-inclusive local governance, targeted education, and skill development (Chaliha, 2022).

4. Conclusion

Despite systemic limitations, women's indigenous knowledge in environmental protection and climate governance cannot be overlooked. Governments and international organizations must take concrete steps to integrate women into climate policy and environmental decision-making. Central and state authorities should enforce meaningful representation of women in local self-government institutions. Establishing dedicated women's sub-committees within Gram Sabhas would provide a formal institutional platform to translate their experiential knowledge into local governance mechanisms. The lived realities of the Mising community demonstrate that indigenous practices offer pragmatic, location-specific climate solutions.

The empirical evidence from the Majuli district underscores that women act as essential vanguards of ecological stewardship and climate resilience. As a vulnerable river island, Majuli contends with recurrent monsoon inundations, severe riverbank erosion, and the loss of arable land. Within this fragile ecology, women have emerged as frontline responders sustaining the local landscape. Their central role in agroecological systems spanning seed preservation, organic farming, flood-adapted agriculture,

and disaster preparedness proves indispensable. Furthermore, women spearhead post-disaster recovery efforts and govern household resources prudently during crises, directly advancing broader sustainable development goals.

In conclusion, this article highlights the imperative of empowering women within environmental protection and climate governance frameworks. By demonstrating the intrinsic link between women's traditional labor and ecological maintenance, the analysis argues that women must occupy a central position in environmental decision-making to achieve lasting equity and resilience. Through their enduring adaptations, the women of Majuli stand as a testament to the transformative power of grassroots environmental stewardship.

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Supplementary Scientific Chapters

24

A Review on Sequestration of Carbon in Wetlands

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ABSTRACT

Wetlands are the most productive ecosystems on Earth, which play a crucial role in the global carbon cycle by acting as significant carbon sinks. As major carbon sinks, wetlands fix atmospheric CO_2 through photosynthesis and store it in biomass and sediments under anaerobic conditions. In wetlands carbon sequestration occurs primarily through photosynthesis by aquatic and semi-aquatic plants that absorb CO_2 and convert it into organic matter. When plant material dies, it accumulates in water-saturated, oxygen-poor (anaerobic) soils, where decomposition is extremely slow, which results in the long-term storage of carbon in sediments and peat layers, making wetlands one of the largest natural carbon sinks on Earth. Various factors, including hydrology, vegetation type, soil composition, and climatic conditions, influence the carbon sequestration potential. In spite of covering a relatively small proportion of the Earth's surface, wetlands store nearly 20–30% of the global soil carbon pool. However, anthropogenic activities are causing significant carbon release back into the atmosphere.

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Therefore, the conservation and restoration of wetlands are of utmost importance. Ecosystem restoration should primarily focus on recovering biodiversity, supporting local livelihoods, and strengthening the resilience of ecosystem services, as the climate mitigation benefits will vary with state transitions among vegetation types. This review synthesizes current understanding of wetland carbon sequestration mechanisms, key controlling factors, global significance, and the challenges that constrain their functioning.

Keywords: *Wetland, Carbon Sequestration, Carbon cycling, Sustainable Development*

1. Introduction

The increasing amount of greenhouse gases in the atmosphere, especially carbon dioxide (CO_2) causes global warming which is one of the burning problems of 21st centuray. Global warming and the associated climate change threaten most of the Earth's ecosystems. The inter-governmental panel on climate change (IPCC) reports a 0.87°C increase in global mean surface temperature and 1.53°C increase in land surface air temperature since 1850–2015 (IPCC, 2014). The high atmospheric CO_2 concentration was mainly contributed by fossil fuel combustions that have been actively occurred since the 20th century. Besides that, land use change includes deforestation, biomass burning, as well as conversion of natural forest to agricultural land, which not only contributes to the increasing CO_2 concentration in the atmosphere, but also causes the increasing of other greenhouse gases (GHGs) like methane (CH_4) and nitrous oxide (N_2O) (Lal 2004).

In the global ecosystem, wetlands are vital carbon sinks, playing a crucial role in absorbing greenhouse gases such as carbon dioxide and mitigating global warming (Mitsch and Gosselink, 2015). Wetlands are unique ecosystems found in nature that provide a wide range of essential services to human communities. They play a crucial ecological role and help reduce the adverse effects of global warming on nearby environments by absorbing and storing carbon within their sediments (Bridgham et al., 2008). The ability and efficiency of wetlands in performing these functions, however, can differ significantly depending on factors such as the type of wetland, its hydrology,

biogeochemistry, weather conditions, and numerous other influences (Nag et al., 2023). Wetlands' various physico-chemical and biological properties play a crucial role in regulating nutrient cycles, including carbon. Based on biogeochemical processes and hydrological conditions, wetlands can either act as net carbon sinks or as sources of greenhouse gases. While wetlands are responsible for about 40% of the world's methane (CH_4) emissions, they also have the highest carbon density among terrestrial ecosystems and possess a greater potential to store additional carbon dioxide (CO_2). Several previous studies have examined the role of wetlands in carbon sequestration, highlighting the importance of sediment soils and living plant communities within these ecosystems as effective carbon sinks (Bedard-Haughn et al., 2006; Duan Xiaonan et. al., 2008; Kayranli et al., 2010). Wetlands play a crucial role in storing carbon and can significantly contribute to mitigating climate change. To achieve carbon sequestration, it is essential to enhance our management practices to reduce methane emissions and increase the capacity of wetlands to store carbon. Furthermore, global warming as a result of climate change born from the industrial revolution puts future human survival at risk and has become a challenge to mitigate gas emissions and conserve ecosystems such as wetlands that absorb CO_2. In this context, the objective of this review was to identify the incident factors of loss of area and carbon sequestration in wetlands that have had an impact on climate change in the global level.

2. Concept of Carbon Sequestration

Carbon sequestration refers to process involved in removal of CO_2 from the atmosphere and its transfer and accumulation into the soil pool of wetlands as soil organic matter (SOM). In other words, sequestration in wetlands involves the photosynthetic removal of CO_2 by wetland producers and its conversion into cellulose and other carbon compounds, which are later transformed from detritus into soil organic matter. Carbon sequestration strategies can be broadly classified into two categories: biological and non-biological. Non-biological methods, however, have limitations concerning their efficiency and the cost involved (Nogia et al., 2016). Biological sequestration refers to the capture and storage of CO_2 through natural processes. In comparison to non-biological methods, biotic techniques are cost-effective and

immediately applicable. Photosynthetic uptake of CO_2 is mainly responsible for the global carbon cycling. About 9 gigatons (Gt) of carbon is released annually into the atmosphere via human activities, of which 5 Gt is naturally absorbed by the aquatic and terrestrial systems (Jansson et al., 2010). Targeting both these systems, biological sequestration strategies include blue carbon sequestration and terrestrial carbon sequestration.

Under natural conditions, terrestrial ecosystems are a sink of atmospheric CO_2 and significantly impact the global carbon cycle (Keenan and Williams, 2018). Through photosynthesis, plants fix atmospheric CO_2 into biomass. A portion of the fixed carbon is ultimately converted into stable soil organic carbon (SOC) by forming organo-mineral complexes. Also, the decomposition of plant biomass contributes to soil inorganic carbon (SIC) by forming carbonates and bicarbonates of calcium, magnesium, potassium, and sodium (Lal et al., 2018).

Wetlands and associated soils constitute a large pedologic pool of carbon. Drainage converts the wetlands from a sink to a large source of CO_2. Wetland restoration by ceasing land-use practices and recovery of SOC stocks is a potential means of mitigation (Hiraishi et al., 2014). Natural factors such as climate, soil properties, hydroperiod, plant microbial communities regulate Wetland C fluxes. The three main processes responsible for carbon sequestration in wetlands include photosynthesis or primary productivity, sedimentation, and nutrient enrichment through external factors (Miria and Khan, 2014). The process of Carbon sequestration is majorly mediated by plants (wetland macrophytes), via photosynthesis. Photosynthesis by producers is the primary process responsible for adding organic matter to the wetland floor. Since wetlands are highly productive ecosystems, their plants can readily sequester carbon from the atmosphere and store it in their standing biomass. During photosynthesis, plants assimilate atmospheric CO_2 into their tissues as simple sugars, which are converted to complex materials such as lignin and cellulose and deposited into leaves, stems and roots, and finally in soil (as soil organic carbon; SOC) when plants die. Most wetland plants are known to use atmospheric CO_2 as their main C source, and because of their high rates of gross primary production compared to terrestrial plants, they have a high assimilation capacity for CO_2.

3. Carbon Cycle

The Carbon Cycle refers to the constant movement of carbon from the land and water through the atmosphere and living organism. Wetlands are vital carbon sinks, covering 6-9% of Earth's surface but storing approximately 35% of terrestrial carbon, balancing photosynthesis - driven sequestration with methane/CO_2 emissions. The carbon sink capacity of terrestrial ecosystem is determined by dynamics of -the ecosystem's carbon cycle. The ecosystem carbon cycle involves the exchange of CO_2 based carbon between ecosystems and their surroundings (Wang et al. 2021). Based on their carbon balance ecosystems can be categorized as either carbon sources or sinks. The continuous changes of carbon cycle in ecosystem influence the ratio of the carbon source and sink. The wetland carbon cycle comprises two types- aerobic and anaerobic. It involves photosynthesis and respiration under aerobic conditions, and primarily CH_4 production under anaerobic conditions. Plant utilizes CO_2 during photosynthesis to synthesize carbohydrate. The respiration of plant in wetlands involves the conversion of carbohydrates into CO_2. In wetlands, organic carbon is converted into CO_2 and CH_4, stored in plants, dead plant matter, microorganisms, or peat. Under anaerobic conditions, CH_4 is also generated and released into the atmosphere. Protecting wetlands is crucial for the atmospheric carbon cycle since a substantial portion of the soil carbon pool is stored within them. When plant productivity exceeds decomposition, net soil carbon accumulation occurs. This process eventually leads to the formation of deep peat deposits, which can accumulate for thousands of years. Therefore, protecting wetlands helps to reduce greenhouse gas emissions.

4. Factors Influencing Carbon Sequestration in wetlands

The carbon sequestration potential of wetlands is enhanced by the intake and release of greenhouse gases in the carbon cycle process. Carbon cycle is regulated by various factors, including hydrology, climate, topography, soils characteristics, vegetation type, and human activities. Furthermore, there are interactions exist between these factors. As a result, the amount of carbon captured and released by wetlands may vary significantly. When estimating the carbon sequestration potential of wetlands,

it is essential to consider the impact of various factors on their carbon storage. One of the major threat in wetland degradation is the climate change (Stewart et.al., 2013). Climate change can influence wetlands through direct and indirect effects such as rising temperatures, changes in rainfall intensity and frequency, droughts, floods, and storm frequency (Ray et al. 2016). As a result of climate change, the decomposition rate of wetlands exceeds the production rate, potentially causing wetlands to transition from sinks to carbon sources, emitting CO_2 and CH_4 into the atmosphere (Laiho 2006).

Rising temperatures, altered precipitation patterns, and increased frequency of extreme weather events can affect plant growth, photosynthesis rates, and carbon storage capacity (Anderegg et. al., 2015). Temperature controls the metabolic activities of microbes and can directly controls the microbial population affecting the soil organic matter (SOM) and production of SOM degrading enzymes in the wetland soils. Warming globally increase plant biomass but also decreases the global carbon pools. Higher temperatures can increase plant respiration, potentially offsetting the benefits of carbon uptake through photosynthesis (Way & Oren, 2010). Additionally, changes in rainfall patterns can affect soil moisture and nutrient availability, influencing plant growth and carbon sequestration efficiency (Zhu et al., 2016).

Deforestation and land-use changes are major threats to global carbon sinks. The conversion of forests, grasslands, and wetlands into agricultural or urban land results in the release of stored carbon into the atmosphere, contributing to increased CO_2 levels (Houghton et al., 2017). For instance, deforestation in tropical regions releases carbon stored in both the biomass and soils of forests, accounting for a significant portion of global greenhouse gas emissions (Baccini et al., 2012). Furthermore, deforestation reduces the future carbon sequestration potential of these areas. The amount of water in a wetland, its fluctuation, and inundation patterns, play a crucial role. Stable, waterlogged conditions lead to anaerobic decomposition, slowing the release of carbon. Water saturation and redox potential determine the rate of organic matter decomposition. Soil characteristics like depth, sediment composition, and redox potential affect decomposition rates. Texture, nutrient content, and microbial activity influence organic matter stabilization.

5. Global Significance of Wetland Carbon Sequestration

Wetlands are crucial components of the global carbon cycle. Wetland systems have been proven to be one of the most important ecosystems for absorbing CO_2 from the atmosphere, mitigating global climate change (Anderson et al., 2009). They provide multiple ecosystem services including carbon storage, water purification, flood control, and biodiversity support. Estimates suggest that wetland soils store approximately 500 gigatons (Gt) of carbon globally, equivalent to about 60% of the carbon contained in the atmosphere (Davidson, 2014). Therefore, exploiting the high carbon sequestration capacity of wetlands is a crucial measure to address global climate change

Conserving, protecting and managing wetlands is a global challenge. At international treaty called "The Conservation on Wetlands" was signed in 1971 to provide framework for national action and international cooperation for conservation and wise use of wetlands and their resources. It is also called Ramsar Convention, named after the city Ramsar in Iran where it was signed. Ramsar sites, are recognized as of significant value not only for the country or the countries in which they are located, but for humanity as a whole.

6. Threats to Wetland Carbon Pools in India

Wetland carbon pools, including significant peatland and coastal "blue carbon" stores, are critically threatened by human activities and climate change. Wetlands in India are under severe threat from rapid urbanization, industrial pollution, land-use conversion for agriculture, hydrological alterations (drainage, damming), pollution, and rising temperatures. Key threats include land encroachment, dumping of waste, invasive species and altered hydrology due to infrastructure development. Over 87% of global wetlands have been lost in the last 300 years, releasing stored carbon into the atmosphere. Wildlife institute of India's survey reveals that 70-80% of individual fresh water marshes and lakes in Gangetic flood plains have been lost in the last five decades. At present, only 50 percent of India's wetlands remain. They are disappearing at 2% to 3% every year. The loss of wetlands leads to environmental and ecological problems, which have a direct impact on socio-economic benefits of the associated populace. Major impacts include significant

biodiversity loss, reduction in water quality and degradation of ecosystem services.

Land-Use Conversion & Degradation- Drainage, dredging, and filling for agriculture, aquaculture, and infrastructure development are primary drivers, removing vegetation and oxidizing organic soil, which releases carbon dioxide.

Hydrological Alteration- Dam construction, water diversion, and groundwater extraction alter water levels, exposing submerged soil to oxygen and causing rapid oxidation of stored carbon.

Climate Change Impacts- Rising temperatures increase evaporation and dryness in wetlands, accelerating the decomposition of organic matter. Sea-level rise can submerge or disrupt coastal mangroves and marshes, potentially releasing stored carbon.

Pollution and Invasive Species- Nutrient loading from agricultural runoff (fertilizers) and sewage causes eutrophication, altering the plant communities that drive carbon sequestration. Invasive species can out compete native plants, disrupting the carbon sequestration cycle.

Microplastics- Accumulation of microplastics in coastal wetlands disrupts sediment carbon processes, affecting microbial activity and suffocating sediment-dwelling organisms that aid in carbon burial. When degraded, wetlands can transition from carbon sinks to net carbon sources, exacerbating global warming.

7. Conservation and Management Strategies

Sustainable management and restoration are vital for maintaining and enhancing wetland carbon sinks. Effective strategies include:

Rewetting- Reversing the drainage of agricultural or degraded wetlands by plugging ditches, removing drainage structures, and blocking drains restores the anaerobic, water-wet conditions necessary for carbon accumulation. Restoring drained wetlands through rewetting stops the decomposition of organic matter that releases CO_2 and methane.

Hydrological Rehabilitation- Restoring natural water flows, such as reconnecting rivers to floodplains, to support wetland biodiversity and carbon storage.

Revegetation- Planting native, high-productivity vegetation (e.g., mangroves, seagrasses) to increase biomass and enhance carbon capture.

Conversion of Degraded Land- Transforming cultivated land or abandoned fish ponds back into wetlands, which can bring the soil carbon density closer to natural levels over time.

Invasive Species Control-Removing invasive species (e.g., *Spartina alterniflora*) and replacing them with native, high-sequestration species to restore ecosystem balance.

8. Future Prospects

The future of carbon sequestration through wetland conservation holds significant promise in addressing climate change. As global temperatures rise and carbon emissions continue to increase, the role of wetlands in capturing and storing carbon is becoming more critical than ever. Their ability to sequester carbon over long periods, coupled with their high carbon density, makes wetlands one of the most effective natural solutions for reducing atmospheric carbon dioxide.

Future prospects also depend on balancing conservation with human needs. Addressing threats such as urban expansion, pollution, and unsustainable agricultural practices is essential to protect wetlands from degradation. Promoting sustainable livelihoods that depend on wetland resources can create partnerships between conservation and local communities, ensuring long-term protection.

9. Conclusion

Wetlands are essential ecosystems that contribute significantly to climate change mitigation through carbon sequestration, as they absorb and store substantial amounts of atmospheric carbon dioxide. In addition to regulating greenhouse gases, wetlands provide ecological services such as flood control, water purification, shoreline protection, and biodiversity conservation. Despite their environmental and socio-economic importance, wetlands are increasingly threatened by urbanization, pollution, deforestation, and unsustainable land-use practices. Effective conservation and restoration strategies, supported by governments, scientists, and local communities, are necessary to preserve these ecosystems. Strengthening wetland management can ensure long-term environmental sustainability, climate resilience, and improved livelihoods for future generations.

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Diversity and Abundance of Pollinating Insects Across Different Habitat Types

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ABSTRACT

The diversity of pollinating insects is essential for the efficient pollination of flowering plants and plays a crucial role in maintaining plant diversity. The abundance of pollinators varies across different habitat types due to differences in floral diversity and abundance, habitat characteristics, and the extent of human disturbance. This study examined three habitat types: natural habitats, agricultural lands, and urban areas. Data were collected using transect walks and insect traps. The results showed that natural habitats, with a greater diversity and abundance of flowering plants, attracted a wider range of pollinating insects. In contrast, habitat fragmentation and human disturbance reduced pollinator diversity and abundance. The findings highlight that maintaining habitats with diverse floral resources is essential for sustaining healthy populations of pollinating insects and ensuring the continued provision of pollination services.

Keywords: *Pollinating Insects, Floral Diversity, Habitat Type, Abundance.*

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1. Introduction

Insect pollinators like butterflies, flies, beetles, and moths, play a fundamental role in plant reproduction and the functioning of ecosystems. The diversity of pollinating insects is essential for maintaining a healthy population of pollinating insects. Pollinating insects play a vital role in maintaining biodiversity and ecosystem stability through reproduction in plants This study aims to study the diversity and abundance of pollinating insects across different habitat types, including natural habitat, agricultural lands and urban areas. Insect pollinators facilitate the transfer of pollen between flowers and thus enable fertilization and fruit production. Pollinators also help to maintain productivity in plants by helping to transfer pollen from one flower to another. This is important for plant productivity because it helps to ensure that plants are able to reproduce and produce seeds. Insect pollinators play a crucial role in global food production and agricultural systems. Pollinating insects transfer the pollen grains from one flower to another unintentionally while nectaring as the pollen grains stick to their body parts. Understanding how pollinator diversity and abundance differ across habitats is essential for developing conservation strategies. This study investigates the diversity and abundance of pollinating insects in three distinct habitat types -natural habitat, agricultural lands and urban areas. Small-bodied insects need less food to survive and reproduce, so they are suitable in urban environments (*Buchholz et.al, 2020, Tscharntke* et.al,2012). Pollinators are an important component of biodiversity due to the vital pollination services they provide to wild flowers (Ollerton et al., 2011) and crops (Klein et al., 2007). Insect pollinators contribute to diversity of crop and in the conservation of plant species. Pollinators play an important role in ecosystem resilience by helping to maintain plant diversity and productivity.

2. Materials and Methods

Study Area: The study was conducted in four different habitat types: natural habitat, agricultural land, and urban area. The study was conducted in Jorhat district of Assam with coordinates 26°46′N to 27°15′N latitude and 94°09′E to 94°47′E longitude. The climate of Jorhat is humid subtropical and experiences high

relative humidity. The study area consists of both natural and human-modified urban areas.

2.1 Sampling Method

Transect Walks: Transects were established in each habitat 50 to 200m in length and 2m on either side for visual counts. Insects visiting flowers were observed and recorded for 20 minutes per transect between 09:00–11:00 hrs on sunny days. A constant slow pace was maintained ,5 to 20m /min depending on visibility.

2.2 Identification

Collected specimens were identified using standard taxonomic keys (Michener, 2007; O'Toole & Raw, 1991).

2.3 Data Analysis

Diversity Index: Shannon–Wiener Diversity Index (H') was calculated to estimate species diversity.

$$H = -\Sigma(pi \cdot \ln(pi))$$

Abundance: Total number of individual pollinators observed per habitat.

3. Results

3.1 Diversity of Pollinating Insects

A total of 37 species of pollinating insects were recorded across the study sites. The natural habitats exhibited the highest diversity, whereas agricultural and urban habitats showed relatively lower diversity. Natural habitats exhibited the highest species richness maintaining a balanced pollinator community throughout the year. Agricultural habitats showed seasonal fluctuations depending on crop flowering, while urban habitats had low abundance and diversity due to limited floral resources and higher human disturbance.

Table 1: Diversity of Pollinating Insects in Three Different Habitat-Natural Habitat, Agricultural Land and Urban Area.

Habitat Type	No. of Species	Shannon Index (H')	Dominant Pollinators
Natural habitat	21	-2.764	Bees (*Apis dorsata),* butterflies (*Papilio demoleus,Papilio polytes,Danaus plexippus)*

Agricultural land	11	-2.304	*Bees (Apis mellifera),* Butterflies *(Pieris canidia)*
Urban areas	5	-1.428	Honey beses(*Apis cerana*), Butterflies (*Papilio demoleus,Pieris brassicae)*

3.2 Abundance of Pollinating Insects

Natural habitat supported higher abundance with greater species diversity, while urban areas showed low abundance. As the number of individuals of pollinating insects is related to natural and diverse landscape, so the abundance of pollinating insects is higher in natural habitat and agricultural land than in Urban areas.

4. Discussion

The findings demonstrate that type of habitat strongly influences diversity of pollinating insects and its abundance. Natural habitat provided a wide range of flowering plants with floral resources and microhabitats, supporting a higher diversity of pollinating insects. Agricultural habitats exhibited high abundance but low diversity, dominated by generalists pollinating insects as it is mostly dominated by one type of species. As the agricultural lands are dominated by paddy fields, and paddy is largely self-pollinating, so insects like bees and butterflies belonging to *Pieridae* family are natural pollinators found. Several families of flies including *Anthomyiidae* and *Chironomidae* are found in the agricultural lands dominated by paddy fields. The diversity of insects in agricultural lands (Paddy fields) helps maintain equilibrium between harmful and beneficial insects. Urban areas supported adaptable species like *Apis cerana,Xylocopa sp, Papilio demoleus,Pieris brassicae* as the urban habitat contains roadside vegetation, homegardens and balcony gardens. Urban development has many negative effects on pollinating insects (Fenoglio et al., 2020; Millard et al., 2021). These species found in urban areas are generalist and feed on more than one type of flower and this trait allow them to adjust in urban areas. These results are consistent with earlier studies (Potts et al., 2010; Winfree et al., 2011) showing that semi-natural habitats harbor the highest pollinator richness, while intensive agriculture and urbanization reduce diversity. This study highlights significant

variation in the diversity and abundance of pollinating insects across habitat types. Urbanization changes the environment in many ways that affect organisms (Alberti,2015), although some species are better equipped than others (Fenoglio et al,2020). Natural habitat shows either richer or more diverse assemblages than urban habitat, with more species representing more taxa, and among which some species have special conservation status. This was expected and in agreement with other studies comparing rural and dense urban habitats (*Deguines* et.al,2012, *Bateset.al 2011).* Urbanization results in a drastic modification of habitats with negative effects on biodiversity (McKinney, 2008). Floral resources are a limiting factor for the populations of all pollinators as pollinating insects rely on the flowering plant species. (Willmer, 2011). Further, there is a very strong relationship between flowering plant species richness and pollinating insect species richness (Ollerton, 2017).

5. Conclusion

This study highlights on the diversity, abundance of pollinating insects across different habitat types. Natural habitat supported higher abundance with greater species diversity, while urban areas and highly disturbed areas showed low abundance. The availability of floral resources played an important role. Habitat degradation due to riverbank erosion, pesticide application, deforestation and various anthropogenic impacts were negatively affecting pollinator abundance. Further long-term monitoring is recommended to understand climate-driven changes in pollinator populations in ecologically sensitive regions like Majuli Island. Overall, the findings emphasize on preserving different habitat types for preservation of pollinating insects and the service they provide to ecosystem.

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