SUSTAINABLE FOREST MANAGEMENT: POLICY PERSPECTIVES FROM INDIA

Ph.D. Thesis

By

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DISCIPLINE OF ECONOMICS

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I hereby certify that the work which is being presented in the thesis entitled **Sustainable Forest Management: Policy perspectives from India** in the partial fulfilment of the requirements for the award of the degree of **DOCTOR OF PHILOSOPHY** and submitted in the **Department of Economics, School of Humanities and Social Sciences, Indian Institute of Technology Indore**, is an authentic record of my own work carried out during the time period from April 2017 to April 2024 under the supervision of Dr. Pritee Sharma, Professor, Discipline of Economics, Research Group Lead -Sustainability Studies, School of Humanities and Social Sciences, Indian Institute of Technology Indore.

The matter presented in this thesis has not been submitted by me for the award of any other degree of this or any other institute.

Kanak Singh 1 July 2025

Signature of the student with date

Kanak Singh

(NAME OF THE PhD STUDENT)

This is to certify that the above statement made by the candidate is correct to the best of my/our knowledge.

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Signature of Thesis Supervisor

July 03, 2025

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Kanak Singh has successfully given his/her Ph.D. Oral Examination held on

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Signature of Thesis Supervisor

(NAME OF THESIS SUPERVISOR)

July 3, 2025; Prof. Pritee Sharma

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Thesis Synopsis

Title of the thesis: **Sustainable Forest Management: Policy perspectives from India**

Introduction

Forests are an essential component in the preservation of global well-being and economic stability. Tropical forests harbor a significant proportion of the Earth's terrestrial biodiversity, accounting for over 80% of it (Brockerhoff et al., 2013; Stafford-Smith et al., 2017; Costanza et al., 2016; Le Blanc, 2015). According to the definition provided by the United Nations (2022), climate change pertains to alterations in temperature and customary weather patterns over an extended period in a particular location. Forest ecosystems encompass the intricate interrelationships among the various plant, animal, and microbial species inhabiting a wooded region. The ecosystems in question exhibit distinct features such as a dense tree canopy, a wide variety of flora and fauna, and efficient cycling of nutrients and water, as noted by Zhang et al. (2017).

Forests are a fundamental resource for provisioning services, which are the tangible goods that nature provides (García-Nieto et al., 2013). The universally recognized significance of forests in the regulation of climate is well-established. According to Mitchell et al. (2013), forests function as carbon sinks by capturing carbon dioxide from the atmosphere. The aforementioned procedure serves to alleviate the effects of human-caused climate change and emphasizes the worldwide significance of forests, as stated by Dickie et al. (2014). It has also been found that forests are deeply intertwined with the cultural fabric of many societies. Forest ecosystems are subject to significant environmental stresses that jeopardize their health, biodiversity, and the wide range of ecosystem services they provide. Forests across the globe are currently contending with the consequences of climate change, facing difficulties in adjusting to swiftly evolving circumstances.

The ecosystem services are facing a significant threat from anthropogenic pressures, with climate change being a major contributor. The ramifications of climate change, including elevated worldwide temperatures, altered precipitation cycles, and severe weather occurrences, have significant consequences for the well-being of forests and their capacity to provide crucial services. Giri et al. (2019) found in their research that in the Western Ghats of India, a hotspot of biodiversity, studies suggest that endemic amphibian and reptile species are increasingly being confined to higher altitudes due to warming temperatures. As a result, it causes changes in compressing their habitable ranges (Srinivasulu, Srinivasulu & Srinivasulu, 2021; Ramachandra & Bharath, 2020). Such shifts can disrupt existing ecological balances, and it also affects the local biodiversity that potentially led to the local extinction of species unable to adapt or migrate. Maringer et al. (2021) implied that the instances of increasing temperatures and changing precipitation patterns can potentially result in drier conditions, which makes forests more susceptible to fire occurrences.

The urgency of sustainability is underscored by various environmental challenges, such as climate change (Costanza et al., 2016) and biodiversity loss (Lu et al., 2015). To address these issues, concerted and immediate action is required (Sachs et al., 2019; Sachs, 2012). Vinuesa et al. (2020) assert that the SDGs offer a comprehensive framework for taking action, with a particular emphasis on the pressing requirement for achieving a harmonious equilibrium between human development and the health of the planet. The second target of Sustainable Development Goal 15 (SDG 15.2) emphasizes the importance of Sustainable Forest Management (SFM). This approach seeks to achieve a harmonious balance between the ecological, socio-economic, and cultural aspects of forests, with the aim of benefiting both current and future generations.

Sustainable Forest Management (SFM) is a concept that is characterized by its dynamic and evolving nature, with the overarching goal of preserving and augmenting the ecological, societal, and economic advantages of forested areas (Linser & Wolfslehner, 2022; Kazama et al., 2021). The concept of forest management involves a variety of undertakings such as conservation, restoration, and sustainable utilisation. Its primary objective is to establish an equilibrium between the demand for forest resources and the maintenance of forest well-being and heterogeneity (Ghajar & Najafi, 2012). The key principles of SFM include maintaining forest productivity and health, conserving biodiversity, protecting soil and water resources, and fulfilling social functions, including respecting indigenous rights and providing benefits to local communities (Agnoletti & Santoro, 2015; MacDicken et al., 2015; Linser & Wolfslehner, 2022). In addition, SFM also advocates for legal and institutional frameworks that support sustainable use, valuation, and local control of forest resources (Brandt, Nolte & Agrawal, 2016).

Research Gap

It is seen that, currently, in the world, studies focusing on sustainable forestry in India have not achieved the desired level yet; hence, the exploration of research efforts based on sustainability and forestry is recommended (Atmiş & Çil, 2013; Jafari et al., 2018). An ideal comprehensive sustainable forest management approach should focus on instantaneous as well as long-term strategies. Therefore, the auxiliary strategy requires long-term as well as short-term goals.

The research gaps identified in the context of sustainable forest management in India are primarily centered around understanding the impact of both climatic and non-climatic factors on forest loss. There is a need for comprehensive studies that examine the effects of temperature, precipitation, CO_2 emissions, industrialization, and agriculture on the degradation of forest resources (Tripathi, 2019). Additionally, the role of institutions in fostering sustainable forest management practices remains underexplored (Jaysawal & Saha, 2014), indicating a gap in understanding how institutional frameworks, policies, and governance mechanisms contribute to or hinder the conservation and sustainable use of forest resources.

Another significant research gap lies in elucidating the contribution of forests to sustainable development in India, especially in terms of economic, social, and environmental dimensions (Islam, Ali & Mithun, 2021). This encompasses assessing how forest ecosystems can support the livelihoods of local communities, contribute to economic growth, and ensure environmental sustainability. Lastly, there is a lack of studies investigating the effectiveness of the criteria and indicator system for sustainable forest management in informing policy decision-making processes in India (Zope, Eldho & Jothiprakash, 2015). This includes understanding how this system can be optimized to address the specific challenges faced by the country in managing its forest resources sustainably.

Based on literature review, the research gaps and research questions have been found for the present research. Therefore, considering the discussion about climate change and other development factors and its effect on forests, some questions have been raised.

- Is there any evidence that climatic factors and non-climatic factors like temperature, precipitation, CO_2 emissions, industrialization and agriculture have an impact on forest loss in India?
- What are the effects of climatic and non-climatic factors in India?
- What role the institutions play in sustainable forest management In India?
- What role do forests have in sustainable development in India?

- Can the criteria and indicator system for sustainable forest management in India can help in the policy decision-making process?

Through these research questions the following specific research objectives are formed. They are as follow:

- To investigate the impact of climatic and non-climatic factors on forest loss?
- To perform institutional analysis for sustainable forest management in India?
- To identify the role of forests in sustainable development by exploring synergies of sustainable forestry with other SDGs and policy integration scope?
- To perform assessment of criteria and indicator system of sustainable forest management with a state case study of Madhya Pradesh?

Conceptual Framework

Forests, by virtue of their ecological complexity, contribute to all these categories of services. They act as natural water purifiers, carbon sinks, soil conservers, and biodiversity sanctuaries. They also provide timber, non-timber forest products, and opportunities for tourism and recreation (Ninan & Inoue, 2014). The hydrological cycle is significantly influenced by forests, as they perform the important functions of water flow regulation and water purification through pollutant filtration (Xie et al., 2017).

Consequently, the management and preservation of forests are not just about maintaining tree populations, but also about ensuring the continued delivery of these crucial ecosystem services to human society. The forest ecosystem services hold significant social value that encompasses various aspects of human welfare, including health, culture, economy, and education.

The illustrations and instances examined underscore the extensive range of these consequences, underscoring the pressing necessity of incorporating climate resilience into forest management methodologies. Given the extensive implications of climate change and developmental factors like urbanization and agriculture expansion on the provision of ecosystem services by forests, it is crucial for policy-making and management practices to embrace a comprehensive and climate sensitive approach. By ensuring the long-term sustainability of forests and the valuable services they provide, it is possible to ultimately contribute to global sustainability objectives.

The gradual development of Sustainable Development Goals (SDGs) serves as evidence of the growing worldwide acknowledgement of the significance of sustainable development in our progressively interlinked planet (Costanza et al., 2016; Griggs et al., 2013). While the journey towards sustainable development has been a complex one, the creation and evolution of the SDGs mark a significant milestone. They reflect an increasing global understanding that sustainable development is not a choice, but a necessity, given our current environmental challenges. The SDGs not only highlight our shared global responsibilities but also point towards potential solutions (Sachs et al., 2019). As such, they are more relevant and crucial than ever.

The indicators furnish quantifiable information for monitoring advancement and directing policy formulation, guaranteeing that endeavors are efficaciously contributing to the objective of sustainable forest management. SDG 15, commonly referred to as Life on Land, centers on safeguarding, rehabilitating, and encouraging sustainable utilization of land-based ecosystems, sustainable management of forests, countering desertification, arresting and reversing land deterioration, and stopping the loss of biodiversity. This is supported by various scholarly sources such as Stafford-Smith et al. (2017), Le Blanc (2015), Lal et al. (2021), and Chankseliani & McCowan (2021).

Assessing SFM's impacts requires a comprehensive and adaptive monitoring framework. A combination of remote sensing technology, ground-based surveys, and participatory methods involving local communities and stakeholders can be used to collect and validate data, enhancing transparency and accountability in forest management (Savari, Eskandari Damaneh & Eskandari Damaneh, 2020; Agnoletti & Santoro, 2015; Brandt, Nolte & Agrawal, 2016). Managing forests in India involves navigating numerous complexities arising from the multiple, often competing, and stakeholders' interests. Conflicts occur between conservation objectives and the livelihood needs of forest-dependent communities. Understanding the roles of various institutions, including central and state governments and non-governmental institutes, involved in managing these forests is crucial.

In the context of natural resource governance, particularly forest governance in India, understanding synergies amongst different SDGs and sustainable forestry as well as policy integration scope have profound implications. A nuanced understanding of how Indian forestry practices align with SDGs can provide a holistic view of forest governance, one that transcends the traditional conservation-focused perspective to encompass broader social, economic, and environmental considerations (Ahmad, 2011; Baumgartner, 2019). SFM must be approached holistically and dynamically, taking into account all of its many components and adapting to changing circumstances and problems.

The Criteria and Indicator (C&I) method provides a formal framework for monitoring, analysing, and reporting on the state and trends of forest management at various scales, making it a useful tool for SFM in this situation (Tewari, 2015). The establishment and execution of an appropriate C&I system in India are currently in their early stages, and several challenges exist, including the absence of consistency, accuracy, and comparability, as highlighted by Kumar et al. (2020). To evaluate and interpret the National criteria and indicator system for sustainable forest management is crucial.

The thesis looks at sustainable forest management in India from four different aspects involving studying impact of climatic and non-climatic factors on forest ecosystems. Plus looking at the governance challenges involved in sustainably managing forests through institutional analysis and policy inter-connections and integrations. Also assessing the criteria and indicator system of SFM (Sustainable Forest Management) from the view of subject experts. This forms the conceptual framework of the thesis. The purpose of this framework is to explore and understand different concepts, key challenges and under pinning concepts to optimize sustainable forest management in Indian context.

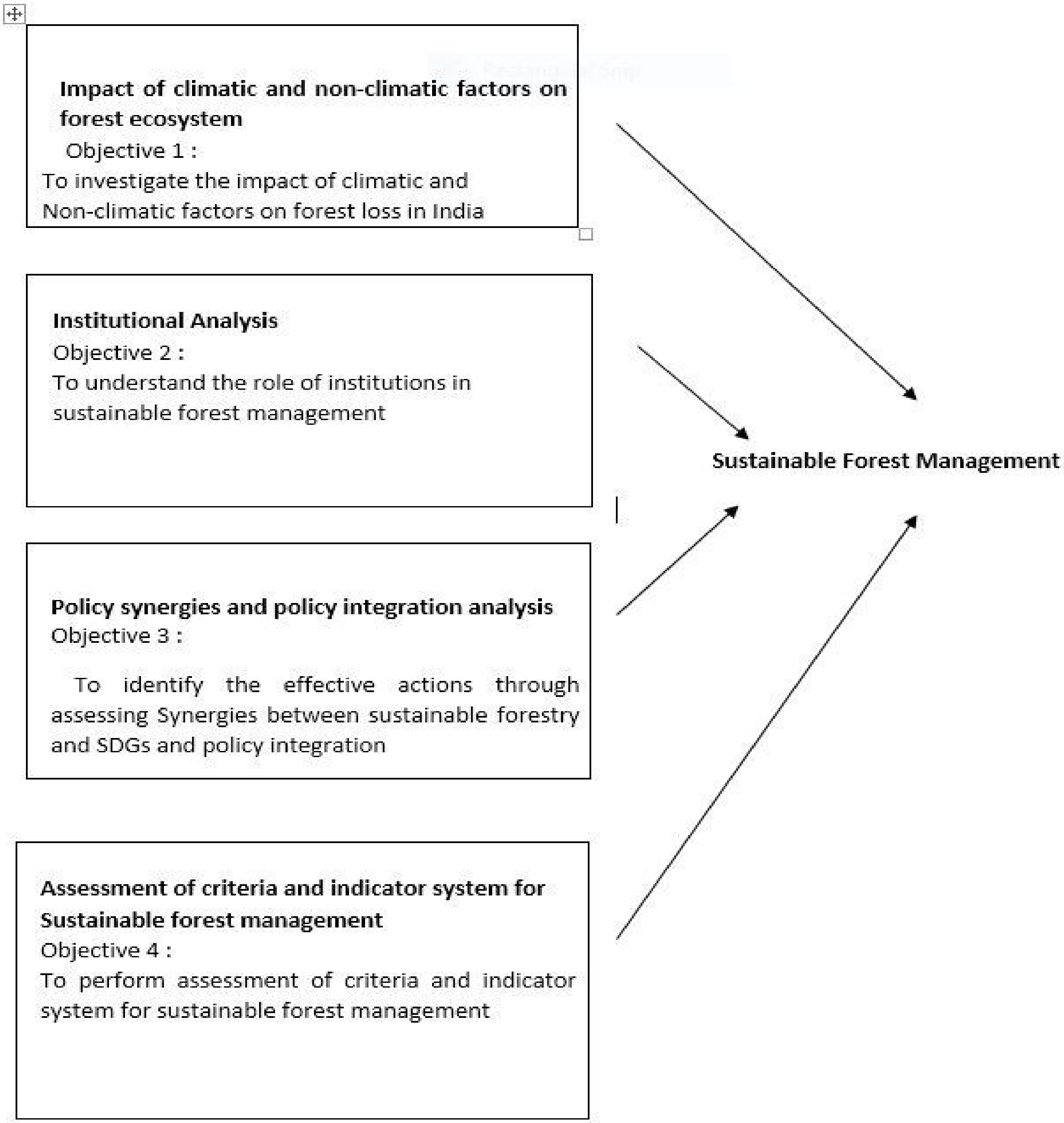

Figure 1: Conceptual framework

Data and Methodology

In the first objective, assessment of the impact of both climatic as well as non-climatic factors together, like temperature, precipitation, CO2 emission and agriculture and urbanization (development proxy) on forest loss at the national level is done. The study used secondary annual time-series database from 1991-2019. The source of data is World Bank data and Indiastat. The expression of the function is as follows:$= f(TA, RA, CO_2, AL, URB)$

The first step is to determine whether the variables are stationary or not. To select the order to integrate study variables, the Augmented Dickey-Fuller (ADF) and Philips-Perron (PP) unit root tests (Philips and Perron, 1988) are done in this study. The ADF test results indicate that the rainfall anomaly (RA) is stationary at a level. While other variables are non-stationary, however, all variables become stationary at first difference. Hence, the ADF test confirms the common order of integration, i.e., I (1). However, we applied another test to check the stationarity of data, i.e., the Phillips-Perron (PP) test shows the same as per results of the ADF test.

This is followed by bound test. In order to quantify the impact of climatic and non-climatic variables on forest loss in India, the study uses an autoregressive distributed lag (ARDL) model. Through detailed research review it is found that the ARDL model has proven to be an invaluable tool in forestry and agriculture research, elucidating intricate relationships and driving informed decision-making. The DOLS (Dynamic ordinary least square model) and CCR (Canonical cointegrating regression model) are also used in this work to test the robustness of ARDL-based long-run outcomes.

In the second objective institutional analysis is done using secondary data and information from various sources. The institutional analysis for sustainable forest management in India is based on theoretical framework developed and adapted from work by Ostrom et al in 1994. The baseline condition has three parts which is physical attribute, community attribute and rules which are already exist for the resource. In this case it is the forest resource. The physical attribute comprises of variables like rate of growth of respective forests, diversity of species present in the forest, climate and weather terrain, size of the resource, temporal and spatial variability, current condition etc. The community attribute includes preferences, distribution of resources, level of common understanding about action situation, accepted norms of behavior etc. Rules include action required, action permitted and action prohibited, sanction etc. Based on the baseline condition of the respective forests the action situation comes into play where actors and situation interact in a pattern for a respective case. This interaction pattern leads to institutional mechanism leading to outcomes. The outcomes have an evaluative criteria which leads policy reforms. The policy reforms then again influence the baseline conditions in different ways.

In the third objective synergies between sustainable forestry and other SDGs is established through Systematic Literature Review (SLR) to delve into the synergy between Sustainable Development Goals (SDGs) and Indian Forest Management. Through SLR, theoretical framework called 'Adapted Sustainable Livelihoods Framework (ASLF)' that incorporates elements from the Sustainable Livelihoods Framework (SLF), Ecosystem Services Framework (ESF), and Natural Capital Theory is developed. The various components of the ASLF, namely Livelihood Assets, Ecosystem Services, Vulnerability Context, Forest Management Practices, Institutional Structures and Processes, and Livelihood Strategies, are interconnected and interdependent, resulting in intricate interactions that shape the outcomes of Sustainable Development. The objective also investigates the connection between forest ecosystems and water resources and their policy integration in Madhya Pradesh, India. It focuses on understanding this interplay and the role of policy networks in enhancing integration. Utilizing qualitative methods, specifically Semi Structured Open-Ended Interviews and MAXQDA software for data analysis, the study gathers insights from public and third-sector officials and subject experts.

In the fourth objective, the National criteria and indicator system for sustainable forest management is assessed through a case study of Madhya Pradesh. This is done by calculating the importance level (weights) of the criteria and indicator system for future policy reforms. The study employs fuzzy logic and Analytical Hierarchy Process (AHP) as a means of mitigating uncertainties in the decision-making process, ultimately resulting in the creation of the Fuzzy AHP technique. While the majority of studies in the field of Sustainable Forest Management (SFM) have relied on the Analytic Hierarchy Process (AHP) as the principal multi-criteria decisionmaking (MCDM) methodology (Haidara et al., 2019; Pourghasemi et al., 2016), this methodology ventures beyond conventional paradigms by adopting the Fuzzy Analytic Hierarchy Process (FAHP).

Main findings

For the first objective is covered in chapter three of the thesis. Through the analysis it is found that the impacts of climate change on forest ecosystems are significant. The coefficient of temperature anomaly is positive but insignificant at 1% significance level. It implies that temperature anomaly deteriorates the forest coverage in India. Similarly, rainfall anomaly has a positive sign and is significant at 1% level of significance. Rainfall anomaly also leads to a decline in forest coverage in India. CO_2 emissions also have a negative effect on forest coverage in India. An increase in CO_2 emissions leads to a decline in forest coverage in India. The study points out that urbanization has negative effect on forest loss, this could be explained as the urbanization increases the percent of stakeholders directly dependent on forest ecosystems are reduced. This happens as more and more population from villages in the forest periphery migrate to cities or urban areas for better prospects. Therefore leading to less dependence on forests.

This study confirmed the long-run cointegration among forest loss and its determinant when forest loss is used as the dependent variable. The study concludes that all climatic variables stimulate forest loss in long run. The empirical findings of this study reveal that the ARDL model has passed all the diagnostic tests successfully.

In the second objective covered in chapter four of the thesis it is found that the role of institutions in sustainable forest management (SFM) in India reveals that institutions play pivotal roles across various aspects, from policy formulation to community engagement and research. Institutions foster policy directions, govern forest conservation efforts, and champion research and education that further underpin SFM. One of the common assumptions made about decentralization is that encouraging local participation, and more equitable sharing of benefits from forest management at the local level, will foster more sustainable use and management of forest resources. Although there are many cases of forests being better protected or rehabilitated after handover to local control and management (for example case studies presented in the chapter), decentralization of forest management can also lead to ecologically unsustainable outcomes and the need for capacity building and development of technical skills are critically important. The decentralization of forest management stands out as a significant development (Colfer and Capistrano, 2012). Although decentralization has brought forth challenges, it has also presented opportunities to empower local communities and evolve institutional capabilities. Capacity needs to be developed at different levels, but especially at the local level; and the process of building capacity has to be sensitive to local culture and vulnerability of forest dependent population.

In the third objective covered in the fifth chapter of the thesis, the analysis conducted reveals that the Sustainable Development Goals (SDGs) have significant effects on every aspect of this framework, thereby necessitating a more sustainable, inclusive, and equitable approach to the management of forests. Nevertheless, this symbiotic relationship also faces various obstacles, including the clash between strategies for sustaining livelihoods and the preservation of forests, as well as disparities in the availability of forest resources. Addressing these challenges necessitates the implementation of comprehensive and tailored strategies that take into account economic, social, and environmental factors. These strategies should be consistent with the principles outlined in the Sustainable Development Goals (SDGs) and should be firmly rooted in the practicalities of local livelihoods and forest ecosystems. Hence, the Afforestation and Sustainable Forest Management Law (ASLF), in conjunction with the Sustainable Development Goals (SDGs), presents a significant framework for improving the management of forests in India, promoting the well-being of local communities, and progressing towards the achievement of wider sustainable development objectives. The present study's analysis and findings make a valuable contribution to the broader comprehension of the interconnections among forest management, sustainable livelihoods, and sustainable development.

In case of policy integration this research delves into the formation and impact of policy networks on forest and water policy integration in India, employing the MAXQDA Code Co-occurrence Model to analyze interview data from stakeholders in forest and water management. The model reveals a network with predominantly weak ties within each sector and a notable absence of strong cross-sectoral ties, indicating limited depth in internal sector collaboration and a lack of integrated approach between the forest and water sectors. Despite recognizing the need for multi-stakeholder collaboration, conflicts of interest and resource scarcity hinder actual integration efforts, as seen in the discord between economic pursuits and conservation goals. Key principles identified include sustainable resource use, community involvement, collaborative decision-making, and leveraging technology for predictive analysis and adaptive management. Inclusivity in decision-making and regular policy reviews are emphasized, ensuring policies remain relevant and effective.

In the sixth chapter, objective four is analyzed. The analysis conducted using the fuzzy Analytic Hierarchy Process (AHP) to evaluate the factors affecting sustainable forest management in India reveals a compelling prioritization of environmental considerations over social and economic factors. This prioritization underscores the critical importance attributed to ecological integrity and ecosystem services in the management of Indian forests. The findings, which emerge from a comprehensive assessment of three main criteria and thirteen sub-criteria, offer a nuanced understanding of sustainable forest management that significantly leans towards environmental sustainability. This outcome points to a strategic focus on environmental sustainability as the cornerstone of forest management practices in India, possibly at the expense of social and economic factors. It highlights the need for an integrated approach that balances ecological integrity with the socio-economic needs of communities dependent on forest resources.

Conclusion and Policy Implications

In the context of addressing the complexities of forest conservation and sustainability, this thesis posited several critical research questions aimed at dissecting the multifaceted interactions between climatic and non-climatic factors and their impact on forest loss in India. Furthermore, the investigation delved into the repercussions of these climatic and non-climatic forces on India's forest ecosystems, aiming to unravel the nuanced ways in which they affect forest health and stability. This comprehensive exploration aimed not only to identify the determinants of forest loss but also to spotlight effective strategies and mechanisms that can bolster forest conservation efforts, thereby contributing to the achievement of sustainable development goals in India. Recognizing the pivotal role of governance, another dimension of our inquiry focused on the contributions of institutional frameworks to the promotion of sustainable forest management practices within the country. This encompasses an examination of how regulatory bodies, policies, and community involvement coalesce to foster or impede the preservation of forest resources.

Institutions play a crucial role in shaping SFM in India by influencing policy formulation, implementation, and governance mechanisms, ensuring the conservation and sustainable use of forest resources. However, challenges persist, including the need for reconciling conflicting objectives and integrating SFM principles into broader land-use planning and policy frameworks. The decentralization of forest management and the involvement of local communities through initiatives like Joint Forest Management (JFM) highlight the potential for more inclusive and sustainable forest governance models.

Additionally, the research scrutinized the function of forests within the broader ambit of sustainable development in India, probing their contribution to ecological balance, economic growth, and social well-being. For example, sustainable forestry projects in India play a significant part in dispute resolution and the acknowledgement of forest rights, which are all important aspects of SDG 16, which focuses on promoting peace, justice, and strong institutions. In summary, policy integration part in chapter five underscores the importance of understanding the forest-water nexus and designing effective policy networks for integrated management. It suggests that while theoretical frameworks provide a basis, practical application in the Indian context reveals gaps that need bridging. Policymakers should focus on strengthening cross-sectoral ties, incorporating community insights, and leveraging technology to ensure effective, sustainable management of forest and water resources.

Lastly, the potential of a criteria and indicator system for sustainable forest management was evaluated for its efficacy in informing policy decision-making processes. It is crucial for global, national, and local policies to acknowledge and bolster the multifaceted role of forests, promoting the incorporation of SFM principles into comprehensive land-use planning and decision-making processes. Aligning economic incentives with the objectives of SFM, through mechanisms such as payment for ecosystem services and green certification schemes is essential.

Limitations

The thesis can be projected in a more in depth analysis of impact of climatic and non-climatic factors for different regions or forest types in India but this is difficult due to lack of data availability, its proper management, data sharing capacity and willingness. This stands true for quantitative, qualitative and geospatial data.

Though this study focused fourth chapter on the themes such as institutional analysis, decentralization and underpinnings of formal and informal set ups, these broad themes are not utilized for the in depth analysis of any other implications like inequalities and lack of coordination at local levels.

It is important to understand that due to the integrated nature of the theme- sustainable forest management, a broader scope of the issue is adapted in the thesis. Though the analysis provided can be diversified and implied into various different projects with in depth analysis. That cannot be inculcated in one project.

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List of Publications Papers

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(i) Journal papers Published:

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List of acronyms

ADF: Augmented Dickey-Fuller

AHP: Analytic Hierarchy Process

AI: Artificial Intelligence

AL: Agriculture Land

ARDL: Auto-regressive Distribution Lag

ASLF: Adapted Sustainable Livelihoods Framework

ATREE: Ashoka Trust for Research in Ecology and the Environment

BNHS: Bombay Natural History Society

C&I: Criteria and Indicators

CAFA: Compensatory Afforestation Fund Act

CCF: Continuous Cover Forestry

CCR: Canonical Cointegrating Regression

CFM: Community Forest Management

CO_2: Carbon dioxide

CO2: Per Capita CO2 emissions

CSR: Corporate Social Responsibility

DOLS: Dynamic Ordinary Least Square

ESF: Ecosystem Services Framework

FAHP: Fuzzy Analytic Hierarchy Process

FAO: Food and Agriculture Organization

FES: Foundation for Ecological Security

FL: Forest Loss

FMOLS: Fully Modified OLS

FRA: Forest Rights Act

FSC: Forest Stewardship Council

FSI: Forest Survey of India

GDP: Gross Domestic Product

GIS: Geographic Information System

IAD: Institutional analysis and development

ICFRE: Indian Council of Forestry Research and Education

ICZM: Integrated Coastal Zone Management

IFS: Indian Forest Service

IGNFA: Indira Gandhi National Forest Academy

IIFM: Indian Institute of Forest Management

IoT: Internet of Things

IPCC: Intergovernmental Panel on Climate Change

ITTO: International Tropical Timber Organization

IWMP: Integrated Watershed Management Programme

JFM: Joint Forest Management

JFMCs: Joint Forest Management Committees

JNNURM: Jawaharlal Nehru National Urban Renewal Mission

LPG: Liquefied Petroleum Gas

MBR: Maya Biosphere Reserve

MCDM: Multi-Criteria Decision Making

MDGs: Millennium Development Goals.

MoEFCC: Ministry of Environment, Forest and Climate Change

N_2O: Nitrous Oxide

NAEB: National Afforestation and Eco-Development Board

NAP: National Afforestation Programme

NAPCC: National Action Plan on Climate Change

NCAP: National Clean Air Programme

NCF: Nature Conservation Foundation

NFP: National Forest Policy

NGO: Non-government organizations

NGT: National Green Tribunal

NTCA: National Tiger Conservation Authority

NTFPs: Non-timber Forest Products

NWAP: National Wildlife Action Plan

OLS: Ordinary Least Squares

PMUY: Pradhan Mantri Ujjwala Yojana

PRI: Panchayati Raj Institutions

RA: Rainfall anomaly

REDD+: Reducing Emissions from Deforestation and Forest Degradation

SDGs: Sustainable Development Goals

SFDCMs: State Forest Departments Coordination Meetings

SFM: Sustainable Forest Management

SLF: Sustainable Livelihoods Framework

SLR: Systematic Literature Review

TA: Temperature Anomaly

UN: United Nations

UNCED: United Nations Conference on Environment and Development

UNFCCC: United Nations Framework Convention on Climate Change

VFCs: Village Forest Committees

WHO: World Health Organization

WTI: Wildlife Trust of India

WWF-India: World Wildlife Fund - India

Chapter 1: Introduction

1.1 Introduction

Forests are an essential component in the preservation of global well-being and economic stability. Tropical forests harbor a significant proportion of the Earth's terrestrial biodiversity, accounting for over 80% of it (Brockerhoff et al., 2013; Stafford-Smith et al., 2017; Costanza et al., 2016; Le Blanc, 2015). Additionally, they are a crucial resource that offers a range of ecosystem services. According to Brunialti (2014), forests serve as innate reservoirs for carbon, sequestering CO2 that would otherwise exist in the atmosphere, and thereby playing a crucial role in ameliorating the effects of climate change. Furthermore, they make a significant contribution to the quality and quantity of water, conservation of soil, and serve as a crucial source of both timber and non-timber products (Morales-Hidalgo, Oswalt & Somanathan, 2015).

The current understanding of climate change attributes its primary cause to anthropogenic or human activities. According to Hansen et al. (2013), the primary factor leading to the phenomenon of global warming is the escalated concentration of greenhouse gases in the Earth's atmosphere, which is primarily attributed to human activities such as industrial processes, deforestation, and the combustion of fossil fuels. The heightened accumulation of greenhouse gases, specifically carbon dioxide (CO2), methane (CH4), and nitrous oxide (N2O), results in the retention of additional solar radiation, culminating in an elevation of the mean global temperature, commonly referred to as global warming (Nadeau & Fuller, 2015).

According to Seidl et al. (2017), the agricultural sector is responsible for approximately 10-12% of the overall anthropogenic greenhouse gas emissions worldwide. This contribution manifests in two main forms: the studies conducted by Cimatti et al. (2021) and García Molinos et al. (2019) focused on the topics of methane production and nitrous oxide emissions. Ruminant animals, namely cows and sheep, generate methane through enteric fermentation, a microbial process that involves the breakdown and fermentation of food in the stomach of these animals (Tei & Sugimoto, 2018; Maringer et al., 2021; Haddad et al., 2015). According to Ussiri and Lal (2017), the global warming potential of methane is 25 times greater than that of CO2 over a 100-year time frame. Therefore, even minor amounts of methane can exert a noteworthy influence on climate change.

Other is the utilization of fertilizers that contain nitrogen in agricultural lands leads to the generation of nitrous oxide, which is a greenhouse gas that possesses a heat-trapping capacity almost 300 times greater than that of CO_2 (Rao et al., 2016; Cimatti et al., 2021; García Molinos et al., 2019). According to Padalia et al. (2019), the release of nitrous oxide is a result of bacterial activity in the soil, whereby nitrogen from fertilisers is broken down and transformed into this greenhouse gas.

According to several studies (Cimatti et al., 2021; Ross et al., 2018; Seidl et al., 2017; Tei & Sugimoto, 2018), the global emission of methane is attributed to solid waste disposal in landfills, accounting for approximately 15% of the total emissions. The process of organic waste decomposition in landfills under anaerobic conditions leads to the generation of methane. Moreover, numerous industrial procedures emit diverse types of greenhouse gases. The manufacturing of cement entails a chemical procedure that emits a noteworthy quantity of carbon dioxide. In addition, certain industrial procedures emit hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and Sulphur hexafluoride (SF_6), which are highly potent greenhouse gases that possess the ability to persist in the atmosphere for extended periods ranging from hundreds to thousands of years (Hansen et al., 2013).

The extraction, processing, and distribution of energy sources have the potential to emit greenhouse gases, as noted by Hamann et al. (2015) and McDowell (2018). The process of extracting and transporting natural gas has been found to result in the release of methane, a greenhouse gas with a high warming potential, as noted by Haddad et al. (2015). Coal mining leads to the emission of methane, which is frequently confined within coal reserves and is discharged during mining operations (Nadeau & Fuller, 2015).

According to Ross et al. (2018), the transport sector contributes approximately 14% of the overall greenhouse gas emissions on a global scale. The principal source of these emissions is the combustion of fossil fuels in transportation modes such as automobiles, trucks, ships, trains, and aircraft. The transportation sector is known to have a significant contribution to greenhouse gas emissions, with cars and trucks being the primary sources of these emissions. This is attributed to the substantial consumption of petrol and diesel fuel, which results in the release of carbon dioxide and other gases into the atmosphere (Maringer et al., 2021). The expansion of the transportation industry is anticipated to result in a corresponding rise in its impact on worldwide greenhouse gas emissions.2

The accumulation of greenhouse gases in the atmosphere is exacerbated by each of these factors, thereby driving the current trend in climate change by intensifying the greenhouse effect. Addressing these challenges necessitates a comprehensive strategy that involves modifications at the personal, communal, and governmental levels.

The notion of sustainability garnered worldwide recognition primarily as a result of the increasing consciousness of the deleterious consequences of human actions on the natural environment and climate. The escalation of worldwide temperatures, changes in precipitation patterns, and the occurrence of extreme weather events have been attributed to climate change, which is primarily caused by the emission of greenhouse gases (Barshis et al., 2013; Teixeira et al., 2013). The alterations are resulting in noteworthy ecological disturbances, which are impacting the diversity of species and the stability of ecosystems (Schmidt, Ivanova & Schäfer, 2013; Rosenzweig et al., 2014).

The phenomenon of climate change is intensifying ecological stressors and posing a threat to the fundamental life-sustaining mechanisms of our planet. According to Harley et al. (2012), the warming and acidification of oceans pose a threat to marine life and coral reef systems. The degradation of land ecosystems is being caused by deforestation, pollution, and changes in land use. These factors are exacerbating the issue of climate change, as noted by Cramer et al. (2018). The recurring exchange of feedback presents significant obstacles to the enduring viability of our planet. Moreover, the worldwide environmental stressors have significant ramifications for the health and welfare of human beings. The occurrence of climate change-induced calamities and the deterioration of ecological systems have the potential to cause malnourishment, psychological disorders, communicable illnesses, and various other health-related apprehensions (McMichael, 2013; Raza et al., 2019).

1.2 Climate Change and Global Environmental Pressures

The latter part of the 1900s witnessed the rise of climate change as a crucial matter on the worldwide schedule, serving as a noteworthy impetus towards achieving a more sustainable future (Luyckx, Tonelli & Stanifer, 2018; Grubb et al., 2019). Griggs et al. (2013) acknowledge that the Intergovernmental Panel on Climate Change (IPCC) played a pioneering role in establishing the scientific consensus on climate change caused by human activities. The recognition of anthropogenic impact on the planetary climate system played a pivotal role in mobilizing worldwide endeavors towards achieving sustainability. The authors Lu et al. (2015) underscore that climate change represents merely one aspect of the various environmental stressors that are affecting the planet on a global scale. Various factors, such as deforestation, biodiversity depletion, water scarcity, and pollution, significantly influence the discourse surrounding global sustainability. The combined effects of these stressors, in conjunction with the phenomenon of climate change, represent a significant threat to the stability and resilience of the worldwide ecosystem. As a result, the imperative for sustainability has become increasingly pressing (Stafford-Smith et al., 2017).

The ramifications of these pressures are extensive, encompassing all facets of society and the economy. Kumar and Vivekadhish (2016) emphasise that environmental pressures exert a noteworthy influence on human health and well-being. This is evidenced by the heightened rates of mortality and morbidity resulting from pollution and climate-related disasters. The authors Handl (2012) and Linnér & Selin (2013) emphasise the importance of adopting comprehensive and interdisciplinary strategies to address the aforementioned stressors, which should encompass health, economic, social, and environmental factors. Vinuesa et al. (2020) assert that the emergence of information and communication technologies, which constitute the digital revolution, presents novel prospects and predicaments in tackling the aforementioned pressures. Digital technologies have the potential to improve monitoring and predictive capabilities, resulting in increased resource efficiency and informed decision-making. Conversely, the digital revolution has the potential to amplify pre-existing disparities and engender fresh sustainability predicaments, such as the proliferation of electronic waste and heightened energy consumption.

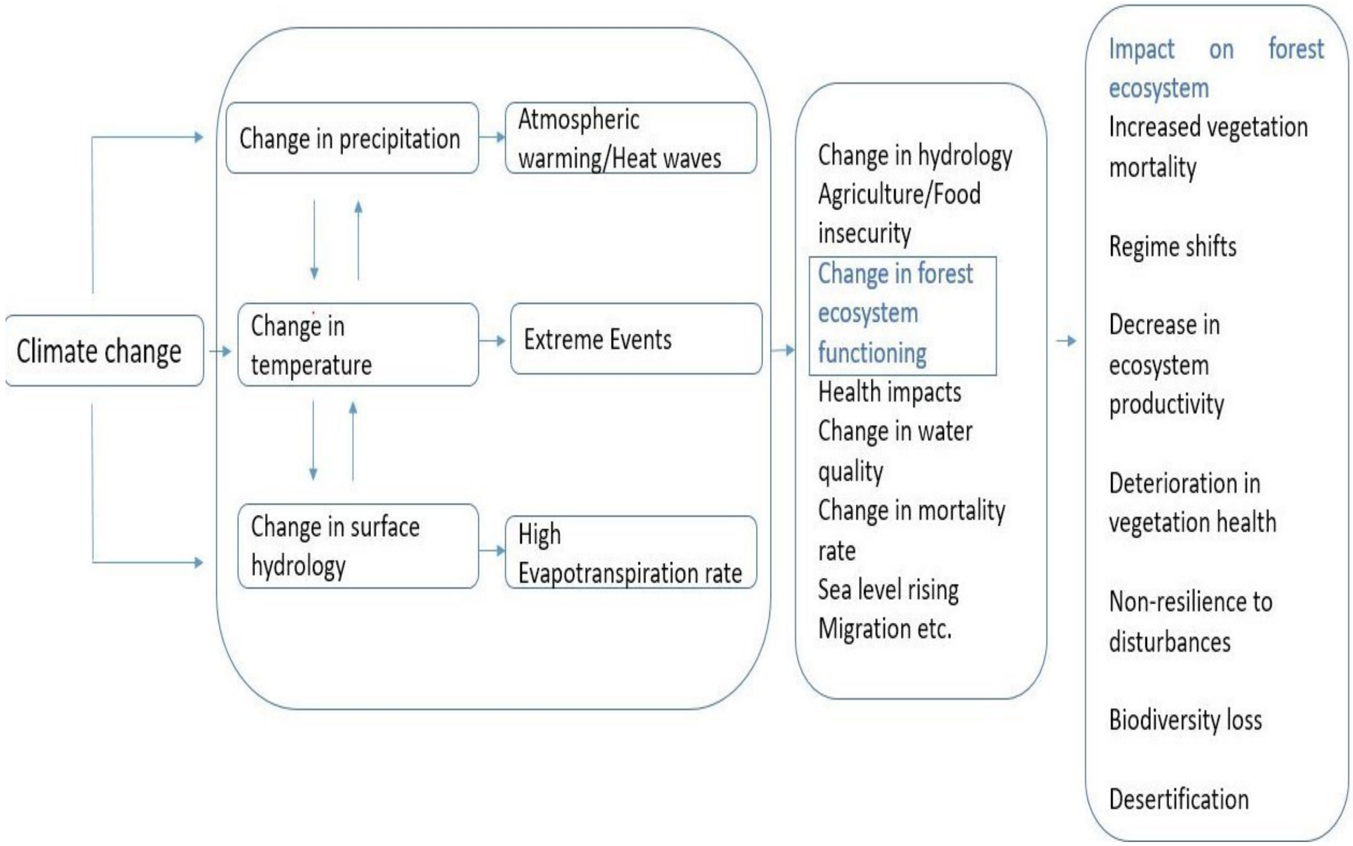

Figure 1.1 Climate change induced impact on forest ecosystem

1.3 Climate change, development and forest ecosystems

Forests are an essential component in the preservation of global well-being and economic stability. Tropical forests harbour a significant proportion of the Earth's terrestrial biodiversity, accounting for over 80% of it (Brockerhoff et al., 2013; Stafford-Smith et al., 2017; Costanza et al., 2016; Le Blanc, 2015). Additionally, they are a crucial resource that offers a range of ecosystem services. According to Brunialti (2014), forests serve as innate reservoirs for carbon, sequestering CO2 that would otherwise exist in the atmosphere, and thereby playing a crucial role in ameliorating the effects of climate change. Furthermore, they make a significant contribution to the quality and quantity of water, conservation of soil, and serve as a crucial source of both timber and non-timber products (Morales-Hidalgo, Oswalt & Somanathan, 2015).

The significance of biodiversity in forests extends beyond the forests themselves, as it plays a pivotal role in bolstering the resilience of ecosystems on a global scale. The presence of a diverse range of species within an ecosystem has been found to have a positive impact on ecosystem productivity, resilience to disturbances, and the stability of ecosystem processes over a prolonged period of time. This has been supported by research conducted by Arroyo-Rodriguez et al. (2020) and Roberge et al. (2013). Hence, the conservation of biodiversity constitutes an essential component of the sustainable management of forests.

According to the definition provided by the United Nations (2022), climate change pertains to alterations in temperature and customary weather patterns over an extended period in a particular location. The phenomenon commonly referred to as climate change is typically linked to the global warming process, which entails alterations in contemporary climate conditions such as the escalation of mean surface temperatures and modifications in precipitation trends. The presence of climate change is widespread and apparent through various phenomena such as the melting of polar ice caps, elevation of sea levels, and the occurrence of more frequent and severe heatwaves, storms, and droughts (Lewis, Edwards & Galbraith, 2015; Pearce-Higgins et al., 2015). The phenomenon of climate change is evidenced by various observable occurrences such as the significant reduction in the size of the Arctic sea ice and glaciers on a global scale. Additionally, there has been a noticeable alteration in the timing of seasonal events such as the blooming of flowers and the migration patterns of animals, which is referred to as phonological shifts as documented by Pearce-Higgins et al. (2015). The escalation in the occurrence of severe weather phenomena such as hurricanes, wildfires, and floods can be ascribed to climate change, as indicated by Maracchi, Sirotenko, and Bindi (2005) and Kale et al. (2016).

Forest ecosystems encompass the intricate interrelationships among the various plant, animal, and microbial species inhabiting a wooded region. The ecosystems in question exhibit distinct features such as a dense tree canopy, a rich variety of flora and fauna, and efficient cycling of nutrients and water, as noted by Zhang et al. (2017). Forests offer a multitude of ecosystem services such as the sequestration of carbon, the purification of water, and the provision of habitat for wildlife. According to Hamann et al. (2015), these areas harbour numerous indigenous communities and serve as a source of sustenance for individuals across the globe.

The phenomenon of climate change has exerted a notable influence on forest ecosystems. A notable instance is the alteration in the geographic range of several tree species towards greater latitudes and elevations, which can be attributed to variations in temperature and precipitation trends. This phenomenon has been documented in various research studies, as reported by Hamann et al.

(2015). This change can alter the species composition of forests, affecting biodiversity and ecosystem functioning. Moreover, increased temperatures and altered rainfall patterns have increased the severity and frequency of forest fires, as evidenced by the devastating fires in Australia in 2019-2020 and in the western United States in recent years (McDowell, 2018). Forest pests and diseases are also expanding their range due to milder winters and longer summer seasons, causing significant damage to forest health and productivity (Jha, Dutt & Bawa, 2000).

Forests are of paramount importance in the mitigation of climate change as they serve as a significant sink for atmospheric carbon dioxide. Therefore, comprehending the potential impact of climate variations on this function is imperative (Ussiri & Lal, 2017; McDowell, 2018; Jha, Dutt & Bawa, 2000; Kale et al., 2016). Furthermore, forests harbour a diverse array of flora and fauna, and alterations in the atmospheric conditions may perturb the intricate equilibrium of these ecological systems, thereby posing a severe threat to the survival of the organisms that rely on them (Liang et al., 2018). Finally, numerous global communities rely on forests as a means of subsistence. Hence, comprehending the ramifications of climate change on forest ecosystems would facilitate the formulation of approaches to conform to and alleviate these consequences, thereby guaranteeing the endurance of these societies (Galbreath, Charles & Oczkowski, 2016).

Regarding the matter of climate change, it encompasses a multitude of interrelated factors, such as rising temperatures, modified precipitation regimes, and a heightened occurrence and severity of anomalous weather phenomena (Ussiri & Lal, 2017). The alterations in question have an impact on the evapotranspiration rate, modify the distribution and conduct of pests and diseases, and may lead to an increase in the frequency and intensity of forest fires, as per Jorgenson et al.'s (2019) findings. Forest ecosystems are intricate and ever-changing, exhibiting significant variation contingent upon geographical location, forest classification, and distinct community compositions (Liang et al., 2018). Forests exhibit active responses to climate impacts and possess adaptive mechanisms to manage specific levels of alteration. The adaptive capacities of forests may face challenges due to the intensity and rapidity of present-day climate change, which can cause alterations in their structure, composition, and functioning, as noted by Chen et al. (2011).

The investigation into the effects of climate change on forest ecosystems is a critical and timely subject matter. The consequences of climate modifications on various forest categories across the globe, as well as their abilities to adjust and potentially alleviate these transformations are critical points to consider. As the investigation into the complex dynamics of this topic progresses, it enhances our capacity to safeguard and maintain the invaluable forest ecosystems of our planet amidst the impacts of environmental and development change (Galbreath, Charles & Oczkowski, 2016; Jorgenson et al., 2019).

A good number of studies (Adeel et al. 2017; Batáry et al., 2015; Lindner et al., 2010; Jaworski & Hilszczański, 2013; Smith, 2012) were conducted in the past to reveal the nature of relationship between agriculture and forest ecosystem. The relationship between agriculture and forest ecosystems is a complex one. Adeel et al. (2017); Petrovic et al. (2015) revealed that they are intrinsically connected through the cycles of nutrients (Batáry et al., 2015), water, and energy that drive both systems. Agriculture requires land, and often this land is sourced from forest areas, leading to deforestation (Lindner et al., 2010). Watson et al. (2018) added to the discussion implying that this change, also known as land-use change, can have significant impacts on the forest ecosystem and the services it provides.

In the context of India, the impacts of urbanization on biodiversity and species composition in forest ecosystems have become progressively evident. The rapid urban expansion, largely unchecked and unregulated in some parts of the country, is leading to the disarray of local ecosystems and subsequent shifts in the biodiversity landscape.

1.4 Sustainability Concept

The study of sustainability is crucial for several reasons. It allows us to understand the consequences of our actions, analyze their potential impacts on future generations, and informs our decision-making process to minimize environmental harm and promote equitable social structures (Kanehisa, 2019). Additionally, it helps businesses and governments identify sustainable practices and policies, encouraging them to shift from linear to circular economic models and to invest in renewable energy sources and green technologies (Mensah, 2019).

Given the accelerating environmental changes and growing socio-economic disparities witnessed in recent decades, the study of sustainability has never been more pertinent. It compels us to reconsider our values, habits, and choices, thereby facilitating a transition towards more sustainable lifestyles and societies (Harwood, 2020). The Sustainable Development Goals (SDGs) were established by the United Nations (UN) in 2015 as a comprehensive initiative to address various complex issues. The SDGs aim to eradicate poverty, safeguard the environment, and promote peace and prosperity for all individuals by 2030, as noted by Lal et al. (2021) and Chankseliani & McCowan (2021). The SDGs have superseded the MDGs and have a wider ambit. They acknowledge that eradicating poverty necessitates a linked implementation of policies that foster economic expansion, cater to various social requirements, and simultaneously combat climate change and safeguard the environment (Davis et al., 2015).

The Sustainable Development Goals (SDGs) comprise a set of 17 interrelated objectives. Among these, SDG 15.2 assumes a pivotal role in addressing climate change, fostering biodiversity, and bolstering human livelihoods by emphasizing sustainable forest management (Cars & West, 2015). According to Günzel-Jensen et al. (2020), sustainability is a multifaceted concept within the framework of the SDGs. It involves the integration of environmental, economic, and social factors to promote a sustainable and viable world for future generations. The SDGs also recognize the importance of global health and its interconnection with sustainable development (World Health Organization, 2015), as well as the need for transparency and accountability in achieving these objectives (Bebbington & Unerman, 2018; Weiss, 2015).

The discourse surrounding sustainability has been notably impacted since the latter half of the 20th century, due to the heightened acknowledgement of climate change and other global environmental stressors (Harwood, 2020; Adams, 2019). The notion of sustainable development was solidified by the Brundtland Report (1987), which acknowledged the worldwide scope of numerous environmental issues and advocated for collaborative efforts and synchronized measures on an international scale (Latapí Agudelo, Jóhannsdóttir & Davídsdóttir, 2019).

In recent years, scholarly investigations have emphasised the pressing need to tackle climate change. Empirical evidence has demonstrated a noteworthy association between human actions and the escalation of worldwide temperatures (Barshis et al., 2013; Harley et al., 2012). The ratification of international agreements, such as the Kyoto Protocol in 1997 and the Paris Agreement in 2015, has been a response to the need to decrease greenhouse gas emissions and restrict global warming, as noted by Tomislav (2018). The discourse on sustainability has been subject to increasing pressures, including but not limited to the loss of biodiversity, pollution, resource scarcity, and socio-economic inequalities. The formulation of the Sustainable

Development Goals (SDGs) by the United Nations in 2015 was driven by the centrality of these issues. The SDGs propose a comprehensive and integrated approach to sustainability, as noted by Purvis, Mao, and Robinson (2019).

To encapsulate, the historical backdrop of sustainability is firmly entrenched in the initial environmental movements and is persistently developing in reaction to worldwide environmental stressors. The implementation of sustainability in our societies requires an interdisciplinary approach due to the intricate interplay between socio-political dynamics and scientific understanding. The sources cited in the text are Mensah (2019) and Kanehisa (2019).

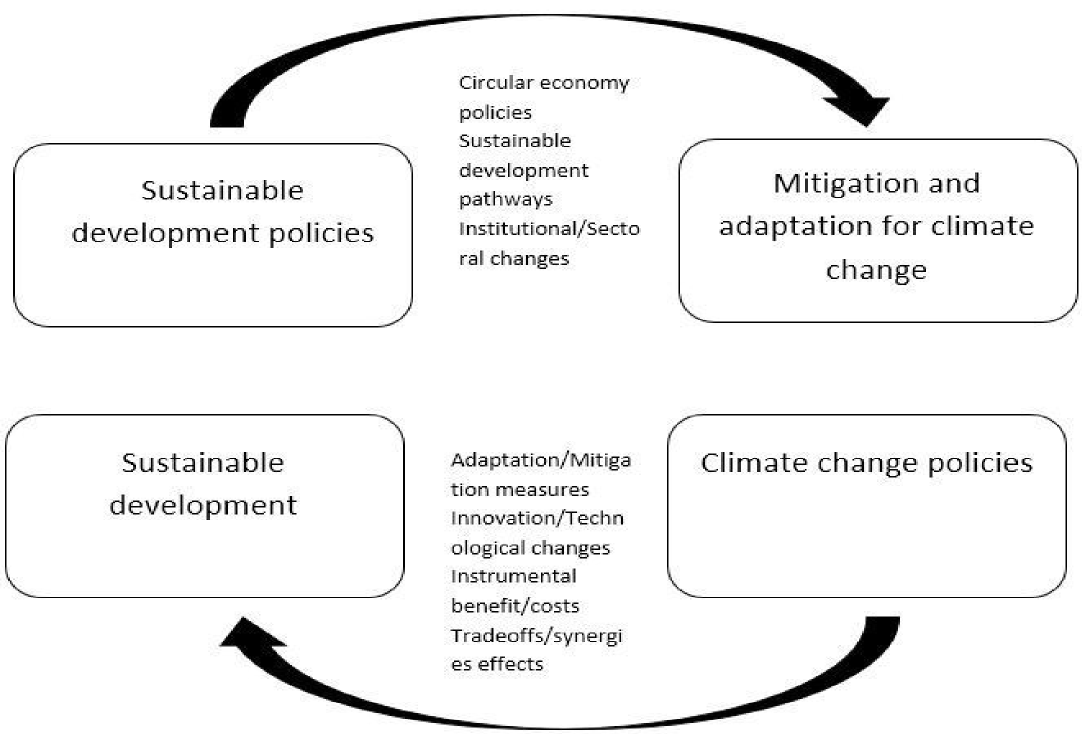

Figure 1.2: Interlinkage between climate change and sustainable development Source: Adapted from Swart et al., (2003).

Amidst the increasing occurrences of environmental disasters, the significance of the Sustainable Development Goals (SDGs) is particularly emphasized. The urgency of sustainability is underscored by various environmental challenges such as climate change (Costanza et al., 2016) and biodiversity loss (Lu et al., 2015). To address these issues, concerted and immediate action is required (Sachs et al., 2019; Sachs, 2012). Vinuesa et al. (2020) assert that the SDGs offer a comprehensive framework for taking action, with a particular emphasis on the pressing requirement for achieving a harmonious equilibrium between human development and the health of the planet. The Sustainable Development Goals (SDGs) have emerged as a fundamental aspect of worldwide development dialogue, providing direction towards a future that is both sustainable and equitable.

While the journey towards sustainable development has been a complex one, the creation and evolution of the SDGs mark a significant milestone. They reflect an increasing global understanding that sustainable development is not a choice, but a necessity, given our current environmental challenges. The SDGs not only highlight our shared global responsibilities but also point towards potential solutions (Sachs et al., 2019). As such, they are more relevant and crucial than ever.

1.5 Sustainable Forest Management

The onset of industrialization during the 18th century instigated a sequence of ecological predicaments, encompassing deforestation, contamination, and depletion of natural resources. The escalation of these hazards prompted a proliferation of conservation initiatives during the late 1800s and early 1900s (Barthel, Parker & Ernstson, 2015; Latapí Agudelo, Jóhannsdóttir & Davídsdóttir, 2019; Kanehisa, 2019). The preservation of wilderness and the judicious utilisation of natural resources were emphasized by these movements, which were mainly concentrated in Europe and the US. This laid the foundation for current concepts of sustainability, as noted by Adams (2019).

Sustainable forestry, as per United Nations Conferences on Environment and Sustainability, is considered one of the most important focal points of sustainable development (Atmiş & Çil, 2013). The definition of sustainability in the forestry sector had a small scope focusing only sustainable wood production initially. Since then, the notion is still evolving (Santos et al., 2019). Now, it can be described as managing and using the forests and forest lands in a manner and at a scale to maintain both the biodiversity, generation capacity, productivity and vitality of forests and their potential local, national and global relevant ecologic, economic and social functions without hampering the needs of now and the future (Mohammadi & Limaei, 2018).

The achievement of SFM (Sustainable Forest Management) necessitates a nuanced equilibrium among economic, social, and environmental objectives, a task that is frequently fraught with difficulty. For example, the economic objective of increasing wood production can conflict with environmental objectives, such as biodiversity conservation (Delabre, Alexander & Rodrigues, 2020). In some instances, local communities may be economically dependent on forest exploitation, leading to unsustainable practices that deplete biodiversity (Sayer et al., 2019). Therefore, there is a need for comprehensive policy and planning that aligns these diverse objectives. Thus, advancing SDG 15.2 necessitates a multifaceted approach that addresses these challenges, integrating SFM principles into broader policy and planning frameworks, ensuring secure land tenure, and aligning economic, social, and environmental objectives.

1.6 Limitations and gaps in approaches for sustainable forest management

It is seen that, currently, in the world the studies focusing on sustainable forestry have not achieved the desired level yet; hence, the exploration of research efforts based on sustainability and forestry is recommended (Atmiş & Çil, 2013; Jafari et al., 2018). An ideal comprehensive sustainable forest management approach should focus on instantaneous as well as the long term strategies. Therefore, the auxiliary strategy requires long term as well as short term goals. A top-down approach based on expert-to-individual based mechanism could play an important role in sustainable forest management. In this context, accurate institutional as well as policy assessment is necessary. The likelihood of extreme events and forest disturbances due to climatic factors is established in many studies. But the thesis present impact of both climatic as well as non-climatic factors together like temperature, precipitation, co2 emission and agriculture and urbanization (development proxy) on forest loss at national level. There are very few studies which present a comprehensive outlook to sustainable forest management. The inter-linkages between climate change and sustainable development is critical to acknowledge. Also, the complexities underscore the need for a more integrated and participatory approach to forest management in India. Therefore the thesis suggests that improving methods for managing the forests with huge diversity and different priorities requires acquiring suitable data, proper idea about the system's interconnections, incorporation of the natural and human factors, and estimation of uncertainties in the projected probabilities. The complexity of climate systems, ecosystem-climatic interactions, interdependence of the institutions make the criteria and indicator system for sustainable forest management assessment process intricate.

Further, the risk due to extreme climatic events, developmental progress and global pressures on forests does not only depend on the scale of the events themselves but also different components of risks involved and action arena inclusive of actors and situations. Therefore, in context of sustainable management of forests, a better understanding of the components and events in terms of their occurrence, dependence on different factors, dynamics and predictability is necessary to further evaluate the implications for sustainable forest management in India. This thesis is an attempt to cover a comprehensive knowledge base for sustainable forest management in India.

1.7 Research Questions

Based on the previous literature survey, the research gaps and research questions have been found out for the present research. Therefore, considering the discussion about climate change and other development factors its effect on forests, some questions have been raised. Also, it is established that sustainable forest management is a sustainability concept which faces specific governance challenges and different monitoring challenges in India. The following research questions try to engage into these challenges and explore respective solutions.

- What are the key principles and dimensions of sustainable forestry?
- What are the major challenges hindering the implementation of sustainable forest management practices globally and in India specifically?
- How do different stakeholders conceptualize and prioritize sustainable forestry goals?
- What are the historical evolution and current trends in sustainable forestry approaches in context of India?
- How do economic, social, and environmental objectives conflict or align in sustainable forest management?
- What are the knowledge gaps and capacity constraints in implementing sustainable forestry practices?
- What is the relative contribution of climatic and non-climatic factors to forest loss in India over the past two decades?
- How do temperature changes, precipitation patterns, and extreme weather events affect forest cover and health?
- How do climatic and non-climatic factors interact to accelerate or mitigate forest loss?
- How effective are current mitigation strategies in addressing climate-induced forest degradation?
- What predictive models can be developed to forecast future forest loss under different climate and development scenarios?
- How do policy interventions moderate the impact of non-climatic factors on forest loss?

- How effective is the current institutional framework for sustainable forest management in India across central, state, and local levels?
- What are the coordination mechanisms between different institutions, and how do institutional conflicts affect forest management outcomes?
- How do formal and informal institutions influence forest governance and community participation in forest management?
- What are the roles and responsibilities of different institutions in forest management, and where do overlaps or gaps exist?
- What institutional innovations have emerged in community-based forest management, and what factors determine their success?
- What capacity building needs exist across different institutional levels?
- How do forest-based livelihoods contribute to rural development and gender empowerment?
- Which SDGs are most directly influenced by forest management practices, and how can these linkages be strengthened?
- How do different stakeholders prioritize and weight various criteria and indicators for sustainable forest management?
- What modifications or improvements are needed in the current C&I framework for better assessment of forest sustainability?
- What mixed-methods approaches are most appropriate for assessing sustainable forest management across different scales and contexts?
- How can research findings be translated into actionable strategies for different stakeholders?

Through these research questions the following specific research objectives are formed. They are as follow:

- To understand the specific concepts/context and issues/challenges in sustainable forestry?
- To investigate the impact of climatic and non-climatic factors on forest loss in India?
- To perform institutional analysis for sustainable forest management in India?
- To identify the role of forests in sustainable development by exploring synergies of sustainable forestry with other SDGs?

- To perform assessment of criteria and indicator system of sustainable forest management with a state case study of Madhya Pradesh?

1.8 Organization of the thesis

Following section presents the organization of the thesis. The thesis is broadly divided into four sections. The first part of the thesis deals with "understanding the resource" comprising Chapter 1and Chapter 2. In this thesis "resource" refers to forest ecosystem. The two chapters form the theoretical background of the thesis. Second part is "impact on resource" comprising chapter 3 which is investigating impact of environmental and global pressure on forest ecosystem. Part three is "meeting the governance challenge" comprising chapters 4, 5 and 6. This section is dedicated to explore the governance aspect of sustainable forest management in India by conducting an institutional analysis, policy analysis and assessment of criteria and indicator system of sustainable forest management in Indian context. The last and fourth section of the thesis is "synthesis". This section presents overall conclusion of the thesis along with detailed policy recommendation and future directions.

Chapter 1 introduces the context of sustainable forest management and gives major insights on the rationale and reasoning of the research performed in the thesis. It shows the major concerns faced by forest ecosystems like climate change and non-climatic factors. The chapter also show the interlinkages between climate change and sustainable development. Research questions and research objectives are mentioned in the chapter along with a brief of thesis organization.

Chapter 2 forms the theoretical background of the thesis. The chapter presents intensive literature review on forest ecosystems, their importance and the impact of climatic and no-climatic factors on them. It mentions the evolution of the concept of "sustainable forest management" from the concepts of sustainability and sustainable development goals. The chapter presents ten global case studies which are essential to provide real-world context and better understanding of how SFM principles are applied in diverse ecological, cultural, social, and economic environments.

Chapter 3 investigates the impact of climatic indicators like temperature, precipitation and CO_2 emission as well as non-climatic pressure indicators like urbanization and agriculture on forest loss of India using ARDL (Auto-regressive distribution lag) model. The chapter also presents detailed theoretical background on the impacts of climatic and non-climatic indicators of forest ecosystems.

Chapter 4 is on Institutional analysis for sustainable forest management in India and addresses the role of institutes in sustainable forest management. The formal and informal mechanisms for coordination amongst different institutes at different level of operations are explored in the chapter. The chapter uses IAD (Institutional analysis and development) framework adapted from Ostrom (1994). The institutes at different levels of governance contribute in sustainable forest management with different strategies and policies according to the respective case and its requirement as shown by ten case studies mentioned in the chapter from across India. The case studies are crucial part of the chapter to understand different challenges and the scale of implementation across the country.

Chapter 5 investigates synergies between forestry and sustainable development goals, while identifying effective actions. The chapter investigates the synergy between sustainable development goals (SDGs) and Indian Forest Management. The chapter presents a theoretical framework called 'Adapted Sustainable Livelihoods Framework (ASLF)' that incorporates elements from the Sustainable Livelihoods Framework (SLF), Ecosystem Services Framework (ESF), and Natural Capital Theory. The analysis and findings make a valuable contribution to the broader comprehension of the interconnections among forest management, sustainable livelihoods, and sustainable development. The chapter also analyze a case study for the state of Madhya Pradesh and connection between forest ecosystems and water resources and their policy integration in Madhya Pradesh, India. It focuses on understanding this interplay and the role of policy networks in enhancing integration. Utilizing qualitative methods, specifically Semi-Structured Open-Ended Interviews and MAXQDA software for data analysis

Chapter 6 presents the assessment of criteria and indicator system for sustainable forest management through a case study of Madhya Pradesh state. The chapter presents application, literature and interpretation of sustainable forest management criteria and indicator system. The chapter presents assessment of criteria and indicator system for sustainable forest management (SFM) using fuzzy analytic hierarchy process for Madhya Pradesh. This is done by calculating the importance level of the C & I. The chapter shows that the importance level of environmental related criteria is more than other criteria in SFM C&I system.

Chapter 7 of the thesis finally shares the conclusion, policy recommendations and future directions of research in this area. Overall summary of all the chapters is used in this chapter to derive major findings, conclusions and policy implications and future scopes about this study.

Summary of the chapter

This chapter provides an introductory overview of the thesis. The chapter talks about climate change and global environmental pressures. . Various factors, such as deforestation, biodiversity depletion, water scarcity, and pollution, significantly influence the discourse surrounding global sustainability. The combined effects of these stressors, in conjunction with the phenomenon of climate change, represent a significant threat to the stability and resilience of the worldwide ecosystem. As a result, the imperative for sustainability has become increasingly pressing (Stafford-Smith et al., 2017).

Through strong literature background it is confirmed that there is a direct link between climate change, development and forest ecosystems. The phenomenon of climate change has exerted a notable influence on forest ecosystems. A notable instance is the alteration in the geographic range of several tree species towards greater latitudes and elevations, which can be attributed to variations in temperature and precipitation trends. This phenomenon has been documented in various research studies, as reported by Hamann et al. (2015).

Amidst the increasing occurrences of environmental disasters, the significance of the Sustainable Development Goals (SDGs) is particularly emphasized. The urgency of sustainability is underscored by various environmental challenges such as climate change (Costanza et al., 2016) and biodiversity loss (Lu et al., 2015). Sustainable forestry, as per United Nations Conferences on Environment and Sustainability, is considered one of the most important focal points of sustainable development (Atmiş & Çil, 2013). The chapter then proceeds and covers limitations and research gaps for sustainable forest management. After the research questions the chapter explains the organization of the thesis.

Chapter 2: Literature Review

2.1 Introduction

According to Mori, Lertzman, and Gustafsson (2017), forests are expanses of land that measure over 0.5 hectares, possess trees that exceed 5 metres in height, and exhibit a canopy cover of more than 10%. These ecosystems are renowned for their abundant biodiversity and valuable natural resources. They perform a crucial function in the provision of ecosystem services, which pertain to the diverse range of advantages that the natural world offers to human society. The services provided can be categorized into four distinct groups: provisioning, which pertains to the production of food and water; regulating, which involves the management of climate and disease; supporting, which encompasses nutrient cycles and crop pollination; and cultural, which includes benefits such as spiritual and recreational activities (García-Nieto et al., 2013).

The phenomenon of climate change is a worldwide occurrence that is marked by alterations in temperature, precipitation patterns, and occurrences of extreme weather events. Its impact is far reaching, affecting various aspects of life, including forest ecosystems. This is supported by research conducted by Ussiri and Lal (2017), Zhang et al. (2017), and Hamann et al. (2015). The forest ecosystems, which are an essential constituent of the biosphere of the Earth, exhibit a distinct interaction with the phenomenon of climate change. They are mutually affected by and have an impact on the evolving climate, as per the findings of Liang et al. (2018). The investigation of the effects of climate change on forest ecosystems is a crucial field of study, owing to their role in carbon sequestration, biodiversity conservation, and the provision of ecosystem services. This has been highlighted in previous research conducted by Chen et al. (2011) and Galbreath, Charles, and Oczkowski (2016).

2.2 Types of Ecosystem Services Provided by Forests

Forests are a fundamental resource for provisioning services, which are the tangible goods that nature provides (García-Nieto et al., 2013). Among these, the most evident is wood. It acts as a fuel source, timber for construction, and raw material for numerous industries such as paper and furniture manufacturing (Smale et al., 2013). Non-timber forest products (NTFPs) encompass a diverse range of commodities, including but not limited to fruits, nuts, berries, mushrooms, medicinal plants, and various other items. According to Boyd et al. (2013), non-timber forest products (NTFPs) play a vital role in the economic and nutritional well-being of rural communities.

In addition, forests have a crucial function in sustaining the hydrological cycle. According to Maes et al. (2016), they facilitate the process of water filtration and regulation, thereby ensuring the availability of water for human consumption and agricultural purposes.

Regulating services comprise the many ways forests help regulate environmental conditions. One vital service is climate regulation, particularly carbon sequestration. According to Mori, Lertzman, and Gustafsson (2017), forests serve as carbon sinks by absorbing atmospheric carbon dioxide, which aids in mitigating the effects of climate change. Moreover, forests make a substantial contribution to the process of air and water purification. According to Escobedo et al. (2019), they have the ability to ensnare aerial pollutants and particulates, thereby enhancing the quality of air. Additionally, Salmond et al. (2016) have reported that they can effectively eliminate water contaminants, leading to the provision of cleaner water sources. Forests play a crucial role in regulating local climate conditions, controlling rainfall patterns, and mitigating soil erosion, thereby contributing significantly to the overall health and stability of the environment.

Forests offer non-material benefits in the form of cultural services. The recreational significance of forests is evident in their utilization as areas for diverse outdoor pursuits such as hiking, camping, and bird-watching, as noted by Seidl et al. (2016). According to Brockerhoff et al. (2017), forests possess significant aesthetic value, which enhances mental health and serves as a muse for artistic, literary, and cultural expressions. They also fulfill spiritual needs for many communities that consider forests sacred. Moreover, forests have significant educational value, offering opportunities for environmental education and research.

Ecological processes that provide assistance to other categories of ecosystem services are commonly referred to as supporting services. According to Dhar, Parrott, and Heckbert (2016), forests play a significant role in the process of soil formation through the decomposition of organic matter, which ultimately leads to improved soil fertility. This is a critical factor for the growth and development of various plant species and other living organisms. Nutrient cycling is a crucial process that enables the transfer and transformation of nutrients within an ecosystem, thereby ensuring their accessibility to all biotic constituents. Furthermore, forests serve as habitats for a diverse range of wildlife species, thereby playing a pivotal role in the preservation of biodiversity. Brockerhoff et al. (2013) assert that the resilience and adaptability of forests are attributed to the varied flora and fauna present within them, highlighting the interdependence of life forms in this ecosystem.

2.3 Importance of Forest Ecosystem Services

2.3.1 Environmental Importance

However, scholarly perspectives vary concerning their relative importance, largely based on differing methodological approaches and regional contexts.

The universally recognized significance of forests in the regulation of climate is well-established. According to Mitchell et al. (2013), forests function as carbon sinks by capturing carbon dioxide from the atmosphere. The aforementioned procedure serves to alleviate the effects of human caused climate change and emphasizes the worldwide significance of forests, as stated by Dickie et al. (2014). However, Adams (2013) highlights the complexities involved in quantifying carbon sequestration, which can depend on forest type, age, and management practices. The Amazon Rainforest, often referred to as the 'lungs of the Earth', absorbs billions of tons of carbon dioxide annually, illustrating a critical role in global climate regulation (Mitchell et al., 2013).

Forests serve as hotspots for biodiversity, housing more than 80% of terrestrial species (Torralba et al., 2016). This biodiversity supports ecosystem resilience and adaptability. However, Turner et al. (2013) caution that overemphasis on commercially valuable species can lead to diminished biodiversity, arguing for a balance between resource extraction and biodiversity conservation. The Borneo Rainforest in Southeast Asia is a prime example of biodiversity conservation, housing more than 3,000 species of trees and hundreds of mammal and bird species, some of which are critically endangered (Torralba et al., 2016).

Although there is a general consensus regarding the significance of this particular service, the extent of forests' impact on water quality may fluctuate based on several factors, including the type of forest and its geographical location (Elmqvist et al., 2015). New York City's clean water supply is a noteworthy example of forests' water purification role. The city sources its water from a forested watershed, which naturally filters the water, eliminating the need for expensive artificial filtration systems (Xie et al., 2017).

According to Dickie et al. (2014), forests provide a diverse range of resources, including both timber and non-timber forest products, which hold considerable economic and subsistence significance. The sustainable extraction rates and the potential long-term impacts of overexploitation are subjects of debate, as noted by Adams (2013). The utilization of African Pterocarpus erinaceus, commonly known as African Rosewood, exemplifies the provision of services. The utilization of trees for furniture and construction purposes has resulted in their overexploitation, thereby rendering them 'vulnerable' as per the IUCN Red List. This highlights the pressing requirement for sustainable management, as stated by Dickie et al. (2014).

In general, the significance of forest ecosystem services is irrefutable. However, there exists a requirement for a nuanced comprehension and meticulous administration to equilibrate varied environmental, economic, and societal necessities.

2.3.2 Social Importance

According to Seidl et al. (2016), forests offer recreational areas that have a positive impact on mental health and general well-being. Engaging in outdoor activities such as hiking, bird-watching, and camping within forested areas can serve as a means of seeking respite from the pressures of urban living, thereby facilitating a reduction in stress levels and promoting mental rejuvenation. As exemplified by Seidl et al.'s (2016) research, the revitalizing impacts of urban forests have been evidenced in metropolitan areas such as Tokyo and New York. However, while the importance of these health benefits is recognized, quantifying them in concrete economic terms and incorporating them into policy-making is a complex task that sparks debate among researchers (Häyhä et al., 2015).

It has also been found that forests are deeply intertwined with the cultural fabric of many societies. Indigenous communities, in particular, often attach spiritual significance to forests. For example, the Daintree Rainforest in Australia holds spiritual importance for the indigenous Kuku Yalanji people, who consider it home to ancestral spirits (Mori, Lertzman & Gustafsson, 2017). Despite this recognition, quantifying and acknowledging these cultural services in forest management policy presents a significant challenge (Ninan & Inoue, 2014).

The significance of forests to the sustenance of rural communities cannot be overstated, as they serve as a source of both timber and non-timber forest products. These resources not only function as a primary revenue stream but also stimulate regional economic activity. The Shea trees

(Vitellaria paradoxa) found in the forests of West Africa are known to produce butter that is utilised in both food and cosmetic industries, thereby serving as a significant source of economic sustenance for the local communities (Ninan & Inoue, 2014). Achieving a harmonious coexistence between economic progress and environmental sustainability is a multifaceted undertaking that necessitates meticulous governance and strategic enactment of policies (Dhar, Parrott & Heckbert, 2016).

Forests serve as 'living laboratories' for environmental education and research. They offer invaluable opportunities for scientists to study diverse ecological processes and species (GarcíaNieto et al., 2013). For example, the Amazon Rainforest is a hub for scientists globally studying biodiversity and climate change impacts. However, while the educational value of forests is broadly recognized, it often seems undervalued when compared to provisioning services (Pereira et al., 2018).

2.3.3 Economic Importance

The forest ecosystem services hold significant economic value and contribute to multiple sectors such as tourism, timber, non-timber forest products, carbon sequestration, and water regulation. Notwithstanding, there exists a divergence of opinions between economists and environmental scientists regarding the optimal methods for assessing and assigning worth to these services. Forests are recognized as significant economic assets due to their capacity to provide both timber and non-timber products, including medicinal plants, fruits, nuts, and other resources (Ninan & Inoue, 2014). For instance, in many parts of Africa, Shea butter, a non-timber product, is a crucial economic resource for rural communities (Ninan & Inoue, 2014). Yet, determining sustainable harvest levels is a complex task that must balance immediate economic benefits with long-term forest health (Mori, Lertzman & Gustafsson, 2017).

Forest-based tourism and recreational activities generate significant income globally, contributing to local and national economies (Boyd et al., 2013). These activities can range from hiking and camping to wildlife viewing. The economic assessment of recreational services is a multifaceted process that may not comprehensively capture their actual worth, thereby resulting in discussions among economists and ecologists (Seidl et al., 2016).

The economic significance of forests in carbon sequestration has been amplified in light of the emergence of carbon markets. According to Thom and Seidl (2016), forests function as carbon sinks by sequestering CO2 from the atmosphere, thereby aiding in the mitigation of climate change. This service is increasingly being monetized through carbon trading schemes, although the methods for valuation remain contested (Miura et al., 2015). Forests also provide vital services in water regulation, contributing to water quality and quantity, reducing flood risks, and maintaining watershed health (Escobedo et al., 2019). These services have direct and indirect economic implications for sectors like agriculture, water supply, and disaster risk reduction. Still, there is ongoing debate about how best to measure and monetize these benefits (Pereira et al., 2018).

In general, although the economic significance of forest ecosystem services is widely acknowledged, it is imperative to account for the intricacies involved in assessing the value of these services. The excessive focus on monetary assessment may result in the disregard of the inherent, cultural, and societal significance of forests, thereby highlighting the necessity for more comprehensive valuation methodologies (Häyhä et al., 2015).

2.4 Impacts of Climate Change on Forest Ecosystems

The phenomenon of climate change has diverse effects on forest ecosystems, which have the potential to cause negative consequences on their biodiversity, structure, and overall functioning. The following are significant effects:

The health, productivity, and survival of forests are directly affected by alterations in temperature and precipitation patterns. Elevated temperatures have the potential to expedite the metabolic processes of trees, which may result in heightened vulnerability to disease and stress (Laube et al., 2013; Seidl et al., 2017; Tei & Sugimoto, 2018). Lewis, Edwards, and Galbraith (2015) reported that the occurrence of heatwaves and droughts in Australia, which were unprecedented, resulted in extensive tree mortality during the previous decade. Conversely, alterations in precipitation patterns have the potential to modify the moisture content of soil, thereby impacting the viability and development of trees. The reduction in precipitation within the Amazon rainforest has resulted in notable mortality of trees and alterations in the composition of species, as reported by Neumann et al. (2017).

The phenomenon of climate change has an impact on the phenology of forest species, which refers to the timing of natural life-cycle events like flowering and fruiting. This can lead to disturbances in ecosystems, as stated by Pearce-Higgins et al. in 2015. Research conducted in Europe has revealed that the advancement of tree species' leafing and flowering times is attributable to rising temperatures, which may have implications for wildlife that depend on these resources as a source of sustenance (Laube et al., 2013; Haddad et al., 2015; Hansen et al., 2013). Additionally, changing climatic conditions can force species to shift their geographical distributions, usually towards higher altitudes or latitudes (Ravindranath et al., 2011). These shifts can disrupt ecosystem functioning and lead to changes in local biodiversity.

Climate change is intensifying forest disturbances like wildfires, pest outbreaks, and diseases. As global temperatures rise, regions experience longer and more intense heatwaves and droughts, creating optimal conditions for wildfires (Wagner et al., 2014; Jha, Dutt & Bawa, 2000; Kale et al., 2016). For instance, increased wildfire activity in California has been linked to prolonged periods of dry and warm conditions (Anderegg et al., 2015). According to Van Der Werf et al. (2017), the extent of land affected by wildfires in the western region of the United States has increased by over two-fold in recent decades, which is attributed to the impact of climate change. Additionally, warmer temperatures are allowing forest pests and diseases to proliferate and expand their geographical ranges. For example, the mountain pine beetle has been causing widespread mortality in pine forests in North America. Warmer winters have allowed more beetles to survive and reproduce, leading to larger infestations (Anderegg et al., 2015). Climate change is also enabling some tree diseases to expand their ranges. In the UK, ash dieback disease has been spreading due to warmer winters (Beland et al., 2019).

The role of forests in mitigating climate change is crucial as they serve as a carbon sink by sequestering and retaining carbon dioxide from the atmosphere. Nevertheless, the phenomenon of climate change poses a significant threat to this pivotal ecosystem service. The potential of forests to sequester carbon may be reduced by the negative impact of increased temperatures and altered precipitation on tree growth and survival, as evidenced by studies conducted by Zhang et al. (2017), Galbreath, Charles, and Oczkowski (2016), and Jorgenson et al. (2019). In addition, disturbances caused by climate change such as wildfires and pest outbreaks have the potential to result in noteworthy carbon emissions. As per Mackey et al. (2020), wildfires have the potential to not only emit carbon that is stored in trees and soil but also reduce the landscape's ability to sequester carbon in the future. Qiu et al. (2020) provide a concerning illustration of the extensive wildfires that occurred in the Siberian taiga during 2020. These wildfires generated substantial carbon emissions, thereby exacerbating the issue of global warming. The effects of climate change can potentially initiate a negative feedback loop, whereby a decrease in the capacity of forests to absorb carbon and an increase in their emissions can exacerbate the rate of climate change.

The alteration of climate conditions has resulted in the need for species to either adapt, migrate, or potentially face extinction, as evidenced by studies conducted by Sandel et al. (2011), Anderegg et al. (2015), and Van Der Werf et al. (2017). Alterations in temperature and precipitation patterns are giving rise to novel ecological circumstances that numerous species may lack the capacity to endure. As indicated by Fuentes-Castillo, Hernández, and Pliscoff (2020), the increase in temperatures in the Himalayas has resulted in the regional disappearance of various tree species that were incapable of adapting or migrating at a sufficient pace. In addition, the alteration of species distributions may result in the exposure of said species to novel predators, competitors, or diseases, which may have adverse effects on their survival (Ravindranath et al., 2011). The depletion of biodiversity has the potential to unsettle ecosystems and result in the forfeiture of ecosystem services, which can have an impact on human societies that are dependent on these services.

2.5 Introduction to the concept of sustainability

The notion of sustainability is inherently interconnected with our societal, economic, and ecological interrelations. The concept entails the simultaneous and balanced pursuit of economic growth, ecological preservation, and societal fairness, commonly illustrated as a triple-bottom-line framework: People, Planet, and Profit (Adams, 2019). The all-encompassing notion aims to achieve equilibrium between current requirements while safeguarding the ability of forthcoming generations to fulfil their own, thereby underscoring the imperative of conserving resources and upholding ecological soundness (Mensah, 2019).

This concept has been extensively discussed in academic literature, as evidenced by the works of Tomislav (2018), Mensah (2019), and Harwood (2020). Subsequently, this principle was extended to encompass the wider scope of resource utilization and ecological governance. The term 'sustainable development' was brought to the forefront by the Brundtland Commission of the

United Nations in 1987, marking a significant moment in history. It was defined as a type of development that caters to the present needs while ensuring that the future generations can meet their own needs without any hindrance. (Adams, 2019; Tomislav, 2018). The notion of sustainability highlighted the interconnectedness of economic, environmental, and social systems, as posited by Latapí Agudelo, Jóhannsdóttir, and Davídsdóttir (2019).

Over time, the notion of sustainability has undergone a development in terms of intricacy and range, giving rise to a multidisciplinary field of inquiry. This field encompasses diverse methodologies and frameworks that have been suggested for gauging and assessing sustainability performance (Adams, 2019). According to Harwood (2020), there has been a transition from a narrow emphasis on environmental concerns and depletion of resources to a comprehensive and inclusive perspective that incorporates economic well-being, equitable social relations, diverse cultural expressions, and active political engagement.

2.5.1 Brundtland Commission and "Sustainable Development"

The Brundtland Commission, officially known as the World Commission on Environment and Development, was formed by the United Nations in 1983 as a response to growing apprehensions regarding the effects of human actions on the environment and development (Olawumi & Chan, 2018; Purvis, Mao & Robinson, 2019). According to Schmidt, Ivanova, and Schäfer (2013), there was a notable change in the worldwide conversation regarding environment and development. The Brundtland Commission's report titled "Our Common Future" in 1987 introduced the concept of sustainable development, which is defined as the type of development that satisfies the current needs while preserving the capacity of future generations to fulfil their own needs. This definition has been cited by Borowy (2013), McManus (2014), and Clayton & Radcliffe (2018) as a significant and influential contribution to the discourse on sustainable development. The definition in question incorporates the environmental, economic, and social dimensions of development and underscores the significance of ensuring fairness between present and future generations. This is supported by sources such as Richardson (2012) and Wall (2018).

The Brundtland Commission is credited with elevating the notion of "sustainable development" to its current prominence. According to the World Commission on Environment and Development, also known as the Commission, sustainable development is characterized as development that satisfies the requirements of the current generation without jeopardizing the capacity of future generations to fulfil their own needs. This definition has been cited by various scholars (Biermann, Kanie & Kim, 2017; Costanza et al., 2016; Griggs et al., 2013). The definition put forth by FukudaParr et al. (2016) was groundbreaking in that it reconciled the frequently conflicting imperatives of economic progress, ecological preservation, and societal fairness, each of which is indispensable for ensuring sustainability.

According to Gupta and Vegelin (2016), the Brundtland Commission's approach to development has served as a foundation for subsequent international agreements, including the United Nations Framework Convention on Climate Change (UNFCCC) and the 2030 Agenda for Sustainable Development. This balanced approach has been embraced by these agreements, as noted by Lu et al. (2015) and Fukuda-Parr et al. (2016). According to Hák, Janoušková, and Moldan (2016), international agreements have played a crucial role in motivating countries to integrate sustainability principles into their respective national policies and strategies.

Notwithstanding the advancements achieved in the realm of sustainable development, persistent obstacles remain. Sachs et al. (2019) have highlighted the necessity of adopting a comprehensive sustainability strategy that can effectively tackle the interrelatedness of the social, economic, and environmental aspects. According to Wu et al. (2018), the achievement of sustainable development necessitates a steadfast dedication to unceasing innovation and adjustment in response to emerging environmental and social challenges.

Furthermore, the practical and conceptual challenges encountered in the implementation of sustainable development have been noteworthy. Le Blanc (2015) examines the challenge of translating worldwide sustainability objectives into domestic settings and executing them at the regional level. The insufficiency of monitoring and evaluation systems for sustainable development initiatives is emphasized by Kumar Kumar and Vivekadhish (2016). Vinuesa et al. (2020) have examined the digital revolution and have concluded that it offers both prospects and difficulties for sustainability. This implies that conventional methods of sustainable development need to be revaluated.

2.5.2 UN Conference on Environment and Development (Rio Earth Summit)

The notion of sustainable development was reinforced on a worldwide level by the Rio Earth Summit that took place in 1992. The conference yielded significant results, including the formulation of the Rio Declaration, Agenda 21, and the Forest Principles. Additionally, it paved the way for the signing of the Convention on Biological Diversity and the Framework Convention on Climate Change. (Gerasimova, 2017; Osborn & Bigg, 2013; Olawumi & Chan, 2018). The Rio Declaration delineated 27 principles that are crucial for sustainable development. The document underscored the significance of participation, cooperation, and common but differentiated responsibilities in attaining sustainability. This assertion is supported by Grubb et al. (2019) and Handl (2012). Agenda 21 was a comprehensive strategy aimed at promoting sustainable development in the 21st century. The initiative necessitated the active participation of various governmental tiers, civil society, and commercial entities, as posited by Linnér and Selin (2013) and Leggett and Carter (2012).

The Rio Summit played a crucial role in elevating the significance of sustainability and paved the way for subsequent global deliberations on sustainable development and climate change (Osborn & Bigg, 2013; Olawumi & Chan, 2018). The concept of sustainability owes its origin and evolution to the Brundtland Commission and the Rio Earth Summit, which played a pivotal role in this regard. Purvis, Mao, and Robinson (2019) and Clayton and Radcliffe (2018) have contributed to the development of a holistic comprehension of sustainability, which serves as the foundation for contemporary strategies aimed at tackling environmental, economic, and social issues.

The genesis of the SDGs can be traced back to the United Nations Conference on Environment and Development, which is colloquially referred to as the Rio Earth Summit, held in 1992. Handl (2012) emphasized that the summit was a momentous occasion that garnered worldwide attention regarding sustainability and established the groundwork for global collaboration on ecological concerns. The Summit yielded significant results, such as the endorsement of Agenda 21, an all-encompassing strategy aimed at advancing sustainable development (Linnér & Selin, 2013). According to Keesstra et al. (2016), the Agenda incorporates principles such as the integration of environmental factors into development planning and the promotion of social equity, which subsequently influenced the development of the SDGs.

2.6 Sustainable Development Goals

The notion originated in the latter part of the 20th century, however, it has undergone substantial development over the years (Hák, Janoušková & Moldan, 2016; Lu et al., 2015; Fukuda-Parr, et al., 2016). At the outset, discussions pertaining to development were primarily centered on the subject of economic expansion. As the public became increasingly cognizant of the ecological deterioration that ensued from uncontrolled expansion, the conversation underwent a transformation. The concept of sustainable development gained global recognition during the 1987 World Commission on Environment and Development. The commission emphasized the necessity of a development model that harmonizes economic growth, social inclusion, and environmental protection (Sachs, 2012).

Subsequently, the United Nations Conference on Environment and Development (UNCED) in 1992 established the aforementioned notion, culminating in the inception of Agenda 21 - an allencompassing strategy for sustainable development (Gupta & Vegelin, 2016; Wu et al., 2018; Kumar Kumar & Vivekadhish, 2016). However, the advancement towards achieving sustainable development has been inconsistent and sluggish, thereby necessitating additional measures (Hák, Janoušková & Moldan, 2016). The United Nations implemented the Millennium Development Goals (MDGs) in the early 21st century with the objective of tackling poverty and various other societal concerns. The Millennium Development Goals (MDGs) were deficient in two notable aspects, namely the absence of a worldwide ecological outlook and the failure to account for the interrelatedness among diverse developmental facets (Le Blanc, 2015).

As a means of addressing the aforementioned limitations and establishing a more comprehensive structure, the United Nations implemented the 17 Sustainable Development Goals (SDGs) in 2015 as a component of its 2030 Agenda for Sustainable Development. This initiative has been documented by Sachs et al. (2019) and Biermann Kanie & Kim (2017). The Sustainable Development Goals (SDGs) represent a comprehensive and globally recognized framework of objectives aimed at tackling a wide range of societal, financial, and ecological issues. StaffordSmith et al. (2017) emphasize the interdependence of these factors and recognize that achieving sustainable development necessitates a comprehensive strategy to address these issues.

The Sustainable Development Goals (SDGs) represent a significant pledge made by the global community to tackle urgent worldwide issues and steer mankind towards a sustainable tomorrow. The genesis of the Sustainable Development Goals (SDGs) can be attributed to preceding global initiatives and conventions.

2.6.1 Millennium Development Goals (MDGs) and Transition to SDGs

The United Nations' introduction of the Millennium Development Goals (MDGs) in 2000 represented a noteworthy advancement towards the attainment of the SDGs. According to Kruk et al. (2018), the Millennium Development Goals (MDGs) established a series of measurable objectives designed to tackle issues such as poverty, malnutrition, illness, gender disparity, and availability of clean water and sanitation. The MDGs faced criticism for their narrow scope and inability to tackle the underlying structural factors contributing to these challenges (Schroeder, Anggraeni & Weber, 2019). The shift from the Millennium Development Goals (MDGs) to the Sustainable Development Goals (SDGs) was motivated by an acknowledgement of the constraints of the former and the necessity for a more all-encompassing strategy towards worldwide progress. Grubb et al. (2019) posit that the Sustainable Development Goals (SDGs) were formulated with the intention of building upon the Millennium Development Goals (MDGs) by encompassing a more extensive array of concerns and accentuating the interrelatedness of the social, economic, and environmental facets of sustainability.

2.6.2 Formation of SDGs by the United Nations in 2015

The establishment of the Sustainable Development Goals (SDGs) by the United Nations in 2015 represented a noteworthy advancement in the realm of international development policy. The Sustainable Development Goals (SDGs) consist of 17 objectives and 169 targets, with the aim of tackling the most urgent global issues and fostering a sustainable, fair, and comprehensive world by the year 2030 (World Health Organisation, 2015).

Schroeder, Anggraeni, and Weber (2019) emphasize the all-encompassing nature of the inclusive development process of the Sustainable Development Goals (SDGs), which entailed extensive engagement with various stakeholders, including civil society, academia, the private sector, and governments. The adoption of an inclusive approach was deemed crucial in order to ensure that the Sustainable Development Goals (SDGs) effectively tackled a wide range of global challenges, encompassing issues such as poverty, inequality, climate change, and sustainable consumption.

Luyckx, Tonelli & Stanifer (2018) have underscored that the SDGs have brought forth a number of novel features in contrast to their antecedents, the MDGs. The aforementioned aspects encompass a universal focus, indicating that the objectives are applicable to all nations, not exclusively to those that are developing. Additionally, there is a more comprehensive evaluation of economic and environmental factors, and a prioritization of partnerships and cooperation to attain the objectives.

The Sustainable Development Goals (SDGs) represent the outcome of numerous global endeavors spanning several decades aimed at achieving sustainable development. The genesis of this initiative was shaped by antecedent endeavors such as the Rio Earth Summit and the MDGs. However, it also embodies a noteworthy progression in the conception of sustainable development and its attainability. According to the World Health Organization (2023), the achievement of the SDGs in the foreseeable future will have a pivotal impact on shaping the course of worldwide sustainability.

2.6.3 Implementation Strategies and Monitoring Frameworks

The efficacy of the SDGs is heavily contingent upon the implementation strategies and monitoring frameworks that are employed (Leggett & Carter, 2012; Le Blanc, 2015). Several nations have incorporated the Sustainable Development Goals (SDGs) into their domestic development strategies, establishing institutional frameworks to supervise their execution (Osborn & Bigg, 2013). Grubler et al. (2018) have noted the introduction of various policies and initiatives, such as green economy strategies, renewable energy targets, and sustainable city planning, at the national level to promote the SDGs. The monitoring of progress towards the Sustainable Development Goals (SDGs) holds equal significance. According to Pradhan et al. (2017), the availability of reliable data and indicators is crucial for monitoring advancements and pinpointing domains that require intervention. The World Bank and the United Nations are examples of entities that have established all-encompassing systems for monitoring Sustainable Development Goals (SDGs), which furnish significant perspectives on advancements at both global and national levels.

2.7 Sustainable Forest Management

The United Nations Sustainable Development Goals (SDGs) outlined in the 2030 Agenda include a particular target, SDG 15.2, which pertains to Sustainable Forest Management (SFM). The objective in question aims to advance the adoption of sustainable forest management practices, put a stop to deforestation, rehabilitate damaged forests, and significantly enhance afforestation and reforestation efforts on a global scale by the year 2020, as per the works of Lal et al. (2021) and Chankseliani & McCowan (2021). The concept of SFM entails a comprehensive strategy that endeavors to sustain and augment the economic, social, and ecological worth of diverse forest ecosystems, with the objective of promoting the welfare of current and future populations (Cars & West, 2015).

The examination of Sustainable Forest Management (SFM) within the framework of Sustainable Development Goal (SDG) 15.2 holds significant significance and presents numerous advantages. According to Lal et al. (2021), the promotion of comprehension regarding the utilization and preservation of forests in a manner that preserves their biodiversity and resilience is emphasized. Moreover, it enables an analysis of the functions that forests serve in mitigating climate change, conserving ecosystems, and bolstering human sustenance (Davis et al., 2015). The investigation of this subject matter provides learners with the necessary expertise and resources to render well-informed judgements and participate in sustainable development tactics (Günzel-Jensen et al., 2020).

Furthermore, the examination of Sustainable Forest Management sheds light on the complex interconnections between forests and human well-being. The provision of crucial services such as the regulation of water, clean air, and disease control by forests has a direct and indirect impact on global health outcomes, as stated by the World Health Organization (2015) and Weiss (2015).

2.8 Sustainable development goal 15: Life on Land

This objective encompasses a diverse array of targets and indicators, which aim to tackle the urgent concerns pertaining to land utilization and preservation.

SDG 15 exhibits a fundamental connection with numerous other SDGs, thereby underscoring the interrelatedness of the objectives. The conservation of forests and biodiversity has the potential to make a positive impact on SDG 13 (Climate Action), as forests serve as inherent carbon sinks (Prevedello, Almeida-Gomes & Lindenmayer, 2018). The authors Joa, Winkel, and Primmer (2018) assert that sustainable forest management has the potential to facilitate the provision of resources and employment opportunities, thereby contributing to the achievement of SDG 8, which pertains to Decent Work and Economic Growth. Tscharntke et al. (2012) assert that the preservation and responsible utilization of land and forests can make a noteworthy contribution to the achievement of SDG 1 (No Poverty) and SDG 2 (Zero Hunger) by guaranteeing that communities are able to sustain themselves and earn a livelihood from these resources. The attainment of SDG 15 is significantly interrelated with the realization of several other SDGs, emphasizing the significance of a comprehensive and holistic strategy towards sustainable development, as highlighted by Stafford-Smith et al. (2017), Costanza et al. (2016), and Le Blanc (2015).This concept has been extensively discussed in literature by MacDicken et al. (2015) and Yovi & Nurrochmat (2018).

The Sustainable Development Goal 15.2 has established specific objectives to be achieved by the year 2020. These objectives include the advancement of sustainable forest management practises, the cessation of deforestation, the rehabilitation of damaged forests, and a significant increase in afforestation and reforestation efforts. This information has been documented in recent studies by Lal et al. (2021) and Chankseliani & McCowan (2021). The assessment of advancements made towards these objectives is aided by various metrics, including but not limited to the percentage of forested land under sustainable management, the proportion of forested land in relation to the total land area, and the pace of deforestation. These indicators have been studied by Kazama et al. (2021), Ghajar and Najafi (2012), and Yovi and Nurrochmat (2018).

2.9 Case Studies and Examples of SFM Implementation

Each case study present unique characteristic of forest, detailing its geographical location, its defining characteristics, and its significance in terms of ecosystem services, environmental importance, or other relevant attributes. Each forest has its unique set of challenges – ranging from deforestation to habitat loss, from climate change impacts to social and economic pressures. Understanding these concerns provides insight into why these forests were identified for sustainable management efforts. By engaging with these case studies, the chapter increases understanding of the practical implications of SFM, appreciating the successes and learning from the challenges. This collection of case studies underscores the profound rationale for sustainable forest management and enhances the capacity to contribute to SFM initiatives, equipping us with a comprehensive, globally-informed perspective. This is a crucial step towards achieving the vision encapsulated in SDG 15.2, where the world's forests are managed sustainably, ensuring their invaluable contributions to life on Earth.

Global case study 1: Amazon Rainforest, Brazil – Implementing selective logging and forest certification programs.

Introduction

The Amazon Rainforest, situated in Brazil, is a highly significant and biodiverse ecosystem on a global scale. The region in question functions as a worldwide asset, fulfilling a crucial role as a carbon sink, impacting precipitation trends, and providing a habitat for a diverse array of organisms (Diez & García, 2012). Deforestation, which is mainly caused by logging and agricultural expansion, presents a substantial peril.

Strategies of sustainable forest management applied.

Significant efforts have been made to restore the Amazon Rainforest, primarily through the implementation of selective logging and forest certification programs (Diez & García, 2012). Selective logging involves the careful extraction of specific trees, minimizing the disruption to the surrounding ecosystem (Asner et al., 2009). This approach, coupled with the promotion of Forest Stewardship Council (FSC) certifications, has been seen as a critical move towards sustainable forest management (Pereira Jr et al., 2002). This combined strategy seeks to promote biodiversity conservation, reduce carbon emissions, and support local economies. The certification process encourages forest managers and businesses to meet certain sustainability standards, which, in turn, help to preserve the rainforest while allowing for economic productivity (Souza Jr, Roberts & Cochrane, 2005).

Impact on Ecosystem Services

The implementation of selective logging and forest certification initiatives has been observed to have significant effects on the provision of ecosystem services. According to Asner et al. (2009), the maintenance of the regenerative capacity of the forest and the enhancement of its carbon sequestration potential can be achieved by decreasing the intensity of logging activities. This holds noteworthy ramifications for climate management. Furthermore, these programs have contributed to the conservation of biodiversity, which is essential for the proper functioning and resilience of ecosystems. Diez and García (2012) argue that the preservation of the abundance of fauna and flora can be achieved through selective logging, which is crucial for maintaining the intricate network of ecological interactions that are necessary for the provision of ecosystem services. Moreover, the programs offer socio-economic advantages. By promoting sustainable practices, the forest can continue to provide timber, non-timber products, and jobs, supporting local and regional economies (Pereira Jr et al., 2002; Souza Jr, Roberts & Cochrane, 2005).

Conclusion

The case study of the Amazon Rainforest highlights the significance of sustainable forest management, particularly with regards to selective logging and forest certification initiatives. The strategies outlined by Asner et al. (2009) and Diez & García (2012) demonstrate a potential avenue for the conservation of biodiversity, the reduction of the impacts of climate change, and the provision of socio-economic advantages. Nevertheless, the sustained allocation of resources towards these initiatives and the provision of strong policy backing are imperative to ensure their efficacy. Furthermore, it is imperative to pursue global initiatives aimed at reducing the demand for unlawfully harvested timber and advocating for certified forest products.

Global case study 2: Eucalyptus Plantations, Australia – Managed timber production, controlled fires.

Where is the forest located?

Eucalyptus plantations are spread across various regions in Australia, with significant concentrations in Victoria, Tasmania, and New South Wales. These forests form a substantial part of Australia's landscape and are particularly found in regions that offer a conducive climate and soils suitable for eucalyptus growth (Keenan & Nitschke, 2016).

Characteristics of the forest.

The Eucalyptus plantations in Australia are characterized by their mono-species stands of fast growing eucalyptus trees (Bowman et al., 2021). These forests have a special capacity to adapt to and flourish in a variety of environmental circumstances. Their deep root system makes them resilient to drought, and they have a remarkable regrowth capacity after disturbances such as fire. The high oil content in their leaves gives them a distinctive aroma (Keenan & Nitschke, 2016).

Why these forests are important?

Eucalyptus forests are economically significant, providing timber, pulpwood, and other forest products (Keenan et al., 2021). Ecologically, they support diverse ecosystems, providing habitat for a variety of species. Eucalyptus forests also have climate-regulating functions due to their carbon sequestration capacity (Keenan & Nitschke, 2016). These forests also play a significant part in managing watersheds because of the control of groundwater that their deep roots provide. Given their significance from an economic, environmental, and social standpoint, efforts have been made to manage these forests sustainably to assure the long-term availability of these services and commodities (Keenan et al., 2021).

What is the concern?

One of the key concerns with eucalyptus plantations in Australia is the risk of intense wildfires. The high oil content in eucalyptus leaves makes them highly flammable, posing significant fire risks. Wildfires not only result in loss of valuable timber but also threaten local biodiversity, carbon storage capacity, and can adversely impact surrounding communities (Keenan et al., 2021). Eucalyptus plantations' extensive root systems and heavy water demand have also sparked worries about their effect on water supply (Bowman et al., 2021).

Strategies of sustainable forest management applied.

Sustainable management of eucalyptus plantations involves a combination of practices aimed at mitigating fire risks and maintaining productivity. This includes controlled burning or 'prescribed fire' strategies to reduce the fuel load and prevent uncontrolled wildfires (Burrows & McCaw, 2013). In addition, regular thinning operations are conducted to manage stand density, improve tree growth, and reduce fire risk. Diversifying tree age classes across the landscape is also a part of sustainable management to ensure continuous timber supply and reduce vulnerability to disturbances (Keenan et al., 2021).

What were the outcomes/success in the respective case study?

These sustainable forest management techniques have enhanced the health of the forest, decreased the frequency of fires, and secured a consistent supply of forest products. Despite challenges, these strategies illustrate that productive timber plantations and fire risk mitigation can co-exist, contributing to the sustainability of Australia's eucalyptus plantations (Keenan et al., 2021).

Global case study 3: Black Forest, Germany – Continuous cover forestry and sustainable timber production.

Where is the forest located?

The Black Forest, also known as Schwarzwald in German, stretches across the southwestern region of Germany (Gustafsson et al., 2020). It is predominantly located in the state of BadenWürttemberg, extending from the town of Pforzheim in the north to Waldshut on the High Rhine in the south (Sotirov et al., 2017). **Characteristics of the forest**

Characterized by its dense, evergreen forests, and picturesque villages, the Black Forest is a unique and rich ecosystem. It is predominately composed of Norway spruce and Silver Fir, interspersed with European Beech and several deciduous species (Gustafsson et al., 2020). The region's topography is distinguished by its high ridges, deep valleys, and numerous swift rivers, contributing to the diversity of habitats it supports (Yousefpour et al., 2013).

Why these forests are important?

The Black Forest is a significant contributor in the provision of diverse ecosystem services. According to Sotirov et al. (2017), the provision of habitat for a diverse range of flora and fauna, carbon sequestration, and climate regulation are among the benefits provided by it. The forest serves as a vital resource for both timber and non-timber forest products, thereby contributing significantly to the local economies. Moreover, its cultural and recreational importance is significant; the forest represents a symbol of German cultural heritage and is a major attraction for tourism (Gustafsson et al., 2020). However, these demands put considerable pressure on the forest, underlining the need for sustainable management.

What is the concern?

The Black Forest is currently experiencing growing concerns regarding forest degradation, which are primarily attributed to unsustainable logging practises and the impacts of climate change (Yousefpour et al., 2013). High demand for timber, combined with climate stressors, have led to decreased forest health, loss of biodiversity, and an altered landscape. This situation has raised questions about the long-term sustainability and resilience of this important forest ecosystem (Kim et al., 2021).

Strategies of sustainable forest management applied.

To counter these issues, Germany has applied a concept called Continuous Cover Forestry (CCF) in the Black Forest. This strategy aims to maintain a continuous forest cover by selective and careful logging, promoting a mixture of tree ages and species (Sikkema et al., 2014). Furthermore, endeavors have been undertaken to enhance the variety of species composition with the aim of bolstering the forest's ability to withstand the impacts of climate change. Yousefpour et al. (2013) have reported the implementation of stringent regulations aimed at managing logging activities in a sustainable manner, thereby facilitating the production of timber and other forest products.

What were the outcomes/success in the respective case study?

Adoption of the CCF strategy in the Black Forest has shown promising results. The overall health of the forest has improved, and the diversity of species has increased, enhancing the forest's resilience against climatic changes (Sikkema et al., 2014). Moreover, the sustainable timber production practices have ensured a steady supply of timber, supporting the local economy without degrading the forest's health (Kim et al., 2021). The aforementioned achievements serve as evidence of the efficacy of sustainable forest management practices in the conservation and improvement of forest ecosystems.

Global case study 4 : FSC Certified Forests, Sweden – Sustainable Forest management and FSC certification.

Where is the forest located?

Sweden boasts expansive woodland regions that cover a significant portion of its landmass, spanning from Scania in the southern region to Lapland in the northern territory, accounting for approximately 57% of the country's total land area (Johansson & Keskitalo, 2014). In this context, the case study pertains to those Swedish forests certified under the Forest Stewardship Council (FSC), spread throughout the country, often forming a part of managed landscapes that blend production and conservation (Elbakidze et al., 2013).

Characteristics of the forest.

Swedish forests are characterized by a mix of tree species, including Scots Pine, Norway Spruce, and several deciduous varieties. They house diverse fauna, such as the iconic moose, lynx, and the endangered wolf (Johansson & Keskitalo, 2014). The forests also provide significant timber and non-timber resources, contributing to Sweden's economic health. Remarkably, these forests are managed under a model of continuous-cover forestry, enabling timber production alongside biodiversity conservation, a blend of functions captured under the FSC certification standards.

Why these forests are important?

Sweden's FSC-certified forests play vital roles from ecological, economic, and social perspectives. Ecologically, they serve as significant carbon sinks, mitigating climate change impacts (Moore et al., 2012). They also maintain biodiversity by providing habitats to a multitude of species, and contribute to the hydrological cycle and soil preservation. Economically, they support Sweden's robust timber industry, with sustainable timber production under the FSC standards contributing to the international market. Socially, the forests are crucial for recreational activities, tourism, and are woven into the cultural fabric of Sweden. They also play a part in Sami reindeer husbandry, a culturally important and traditional livelihood in northern Sweden. The FSC certification ensures these forests are managed sustainably, preserving these diverse roles for the future (Elbakidze et al., 2013).

What is the concern?

While the Swedish forest sector has made strides towards sustainable forest management, concerns persist. Deforestation due to timber harvesting, albeit at a sustainable rate, impacts biodiversity (Pezdevšek Malovrh et al., 2019). The issue of climate change poses an additional obstacle, as rising temperatures and a heightened occurrence of severe weather phenomena impede the wellbeing and efficiency of forests. The increasing demand for biofuels, considering Sweden's aim to be fossil fuel-free by 2040, may exert pressure on forest resources. Additionally, potential conflicts exist between timber production, conservation goals, and Sami reindeer husbandry, requiring careful balancing of diverse interests under the FSC certification (Elbakidze et al., 2022).

Strategies of sustainable forest management applied.

The FSC certification has been incorporated as a fundamental component of Sweden's approach to sustainable forest management. The certification standards promote sustainable harvesting techniques that aim to minimise environmental impacts while maintaining a consistent supply of timber (Johansson & Keskitalo, 2014). The FSC criteria also enforce the maintenance of high conservation value forests, protecting critical habitats. Additionally, the criteria demand that forest management practises preserve the Sami people's right to continue using their traditional methods of reindeer herding. Strategies such as continuous-cover forestry, where some trees are always kept standing to ensure forest cover and biodiversity, are also employed. The FSC also necessitates active stakeholder engagement, ensuring diverse interests are considered in forest management planning (Elbakidze et al., 2022).

What were the outcomes?

The adoption of the FSC criteria in Swedish forests has resulted in improved forest management from an environmental, social, and economic standpoint. It has promoted sustainable timber production while conserving biodiversity (Moore et al., 2012). The balance between timber production and conservation has increased market acceptance of Swedish wood products, boosting the economy. Importantly, it has promoted more inclusive decision-making processes, accounting for diverse stakeholder interests, including those of the Sami people. Despite the persisting challenges, Sweden's FSC-certified forests demonstrate a proactive model of sustainable forest management (Elbakidze et al., 2013).

Global case study 5: Kakamega Forest, Kenya – Community-based conservation, agroforestry.

Where is the forest located?

About 415 kilometres from Nairobi, in Kenya's Western Province, is where you'll find the Kakamega Forest. This tropical rainforest covers an area of around 238 square kilometres and is the only one of its type in Kenya (Tebkew & Atinkut, 2022). The forest is vital to Kenya's environmental and cultural framework because of its distinctive biological location in the heart of the country's highlands (Nyang'au et al., 2020).

Characteristics of the forest.

The Kakamega Forest hosts a rich biodiversity with over 380 recorded bird species, 400 butterfly species, and numerous endemic species. The forest is characterized by dense vegetation, composed of a variety of trees, shrubs, herbs, and climbers. Furthermore, it is one of the few tropical rainforests that lies outside the tropics, which contributes to its unique ecosystem and makes it a biodiversity hotspot (Andole et al., 2020).

Why these forests are important?

The Kakamega Forest's significance stems from its environmental, cultural, and economic benefits. It contributes considerably to attempts to mitigate global climate change by providing essential ecosystem services such as carbon sequestration, water catchment, and biodiversity protection (Nyang'au et al., 2020). The forest also provides a vital home for a wide variety of species, some of which are local favorites. It has spiritual importance for the nearby Luhya population from a cultural standpoint. The forest is an essential resource for sustainable development because it generates income for local people via non-timber forest products and ecotourism (Mutoko et al., 2015).

What is the concern?

The principal concerns surrounding the Kakamega Forest are deforestation and habitat loss, fueled by human encroachment, agricultural expansion, illegal logging, and charcoal production. These activities have led to significant biodiversity loss and ecosystem degradation, posing a threat to the forest's long-term sustainability (Nyang'au et al., 2020). The ability of the forest to deliver essential ecosystem services is also compromised by the loss of forest cover, which has an impact on both local and global environmental stability. Due to these difficulties, the forest has to be managed sustainably and conserved (Ondiba & Matsui, 2021).

Strategies of sustainable forest management applied.

Agroforestry and community-based conservation have been used to solve these issues. These tactics encourage local people' involvement in forest management, which improves ownership and assures sustainable usage (Mutoko et al., 2015). Agroforestry systems, which incorporate trees into farmland, have been promoted to provide livelihood benefits and reduce pressure on the forest. These measures are accompanied by awareness campaigns and education programs to enhance community understanding of the forest's importance and the need for its conservation (Tebkew & Atinkut, 2022).

2.10 Conclusion

To mitigate the impacts of climate change on forest ecosystems and optimize their resilience, effective adaptive strategies and forest management responses must be implemented. These strategies often include forest restoration, assisted migration of tree species, altered forest management practices, and increased genetic diversity.

The achievement of SDG 15.2 and the implementation of Sustainable Forest Management (SFM) have significant potential for effectively addressing environmental and socio-economic challenges.

The chapter suggests to advance the sustainable usage and administration of forest resources, while concurrently preserving biodiversity, making substantial contributions to the mitigation of climate change, and improving the quality of life, particularly for communities that rely on forests. Despite this potential, various challenges need to be addressed, including balancing multiple objectives and integrating SFM into broader land-use planning and policy.

As we move forward, the critical task lies in continuing to evolve and refine the SFM concept and practices, informed by ongoing research, monitoring, and local experience. Global, national, and local policy needs to recognize and support the complex role of forests, promoting the integration of SFM principles into broader land-use planning and decision-making. It is imperative to ensure that economic incentives are congruent with sustainable forest management (SFM) goals, which can be achieved through mechanisms such as payment for ecosystem services and green certification.

Finally, case studies suggests that landscape approach holds significant merit, as it takes into account forests within the wider framework of land-use systems, encompassing agriculture, infrastructure, and human settlements. This approach can help in managing trade-offs and synergies between different land uses, ensuring that all sectors contribute to the shared goals of sustainability. In essence, the future of SDG 15.2 and SFM lies in a collective, concerted, and integrated approach that recognizes and values forests' multi-functionality for our planet and future generations.

The critical part that forests play, not only in maintaining ecological balance but also in contributing to social and economic sustainability. Building on that understanding, it is now vital to delve into a more practical dimension of SFM by examining actual instances where this theoretical framework has been applied.

Summary of the chapter

Forest ecosystem are fundamentally crucial for sustenance of the planet. They have prominent role in climate regulation, biodiversity conversation, and water purification and have capacity to provide essential resources. The first section of the thesis is “Understanding the forest resource”. This chapter precisely helps to understand the importance of forest ecosystem by discussing the different types of ecosystem services forest provides and their environmental, social and economic importance; the impact of environmental and global changes on forests. The chapter then drive into the need for sustainability, the concept of sustainable development, evolution of sustainable development goals (SDGs) and sustainable forest management.

It is well established that climate change is predominantly driven by anthropogenic greenhouse gas emissions, is a global environmental concern manifesting in rising average temperatures, altering weather patterns, and escalating extreme weather events (Prather et al., 2013). It poses a significant threat to the planet's ecological balance, leading to severe implications for ecosystems and biodiversity. Among the most affected ecosystems are forests, given their sensitivity to climatic variations. The impacts of climate change on forest ecosystem involves temperature and precipitation changes, phenology and species distribution shifts, forest disturbance (wildfires, pests and diseases), carbon sequestration and storage changes, biodiversity loss and species extinctions. The chapter also discusses the effects of climate change on provisioning and regulating services provided by forest ecosystems.

The environmental and global pressures on all resources of the planet lead to the evolution of concept of sustainability. It is important to go through the evolution of the concept of sustainability and formation of sustainable development goals because the thesis is based on the concepts of sustainable forest management. The notion of sustainability is inherently interconnected with our societal, economic, and ecological interrelations. The concept entails the simultaneous and balanced pursuit of economic growth, ecological preservation, and societal fairness, commonly illustrated as a triple-bottom-line framework: People, Planet, and Profit (Adams, 2019). The Sustainable Development Goals (SDGs), which were adopted in 2015 by the United Nations, represent a significant advancement in the field of sustainability. Grubb et al. (2019) assert that the Sustainable Development Goals (SDGs) were formulated with the intention of building upon the Millennium Development Goals (MDGs) by encompassing a more extensive array of concerns and accentuating the interrelatedness of the social, economic, and environmental facets of sustainability. According to the World Health Organization (2023), the achievement of the SDGs in the foreseeable future will have a pivotal impact on shaping the course of worldwide sustainability. The practical and conceptual challenges encountered in the implementation of sustainable development have been noteworthy. As a means of addressing the limitations and establishing a more comprehensive structure, the United Nations implemented the 17 Sustainable

Development Goals (SDGs) in 2015 as a component of its 2030 Agenda for Sustainable Development.

The United Nations Sustainable Development Goals (SDGs) outlined in the 2030 Agenda include a particular target, SDG 15.2, which pertains to Sustainable Forest Management (SFM). The examination of Sustainable Forest Management (SFM) within the framework of Sustainable Development Goal (SDG) 15.2 holds significant significance and presents numerous advantages. The examination of Sustainable Forest Management sheds light on the complex interconnections between forests and human well-being. Exploring the SDG 15.2 objective fosters comprehension regarding the importance of transparency and accountability in natural resource management, emphasizing the function of social and environmental reporting in sustainable development, as posited by Bebbington and Unerman (2018). This chapter serves to emphasize the significance of forests in sustainable development and sustainable forest management.

The chapter presents five global case studies which are essential to provide real-world context and better understanding of how SFM principles are applied in diverse ecological, cultural, social, and economic environments. They highlight the complexities and intricacies involved in translating theory into practice and demonstrate the iterative and adaptive nature of sustainable management. The chapter provide the theoretical background and rationale of the thesis.

Chapter 3: Impact of climatic and non-climatic factors on forest loss in India: A theoretical and empirical review

3.1 Introduction: Overview of climate change and its drivers

Climate change refers to the long-term shifts in global weather patterns and temperatures that have occurred since the Industrial Revolution (United Nations, 2022; Haughan et al., 2022; Choe & Thorne, 2017). It is primarily caused by human activities such as burning fossil fuels (Gopalakrishnan et al., 2011; Carroll et al., 2015), deforestation and agriculture (Corlett & Westcott, 2013; Choe & Thorne, 2017) because these activities release large amounts of greenhouse gases into the atmosphere. These gases trap heat from the sun, causing the earth's temperature to rise and leading to a wide range of environmental impacts, including more extreme weather events, melting ice caps, rising sea levels, and changes in ecosystems and wildlife behavior.

Brosch (2021) identified that the burning of fossil fuels is a primary driver of climate change. When individual burn fossil fuels like coal, oil, and natural gas for energy or transportation, they release large amounts of carbon dioxide (CO_2) into the atmosphere. This CO_2, being a potent greenhouse gas, traps heat from the sun, leading to a rise in global temperatures (Das & Behera, 2013). Likewise, Choe & Thorne (2017) reported that deforestation is another significant contributor to climate change. Forests act as carbon sinks, absorbing CO_2 from the atmosphere. However, when these forests are cut down, the stored carbon is released back into the atmosphere, further exacerbating global warming (Brosch, 2021). Furthermore, the loss of forests also means a reduction in the capacity to absorb future CO_2 emissions.

Agriculture and animal husbandry have also been identified as drivers of climate change (PearceHiggins et al., 2015; Haughan et al., 2022; Choe & Thorne, 2017). These activities produce significant quantities of methane (CH_4), another potent greenhouse gas. Livestock such as cows and sheep produce methane as part of their digestive process, while rice cultivation and the decay of organic waste in landfills also generate substantial amounts of this gas. Industrial processes, as Galbreath, Charles & Oczkowski (2016) highlighted, contribute significantly to greenhouse gas emissions. These processes often involve the combustion of fossil fuels, leading to the emission of CO_2. Additionally, some industrial processes release other potent greenhouse gases such as hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and Sulphur hexafluoride (SF_6).

Land use changes (Haughan et al., 2022), particularly urbanization and changes in land use for agriculture, also contribute to climate change (Jorgenson et al., 2019; Das & Behera, 2013). These changes often lead to the loss of natural habitats that serve as carbon sinks, such as forests and wetlands, and increase the proportion of land covered by hard surfaces, which can contribute to the urban heat island effect. On the other hand, transportation and travel, largely powered by the burning of fossil fuels, also contribute significantly to greenhouse gas emissions (Fahey et al., 2017). Cars, trucks, airplanes, and ships all burn large amounts of gasoline and diesel fuel, releasing CO2 into the atmosphere.

3.2 Linkages between climate change and forest ecosystems

Climate change is one of the world's greatest challenges (Ussiri & Lal, 2017; Ravindranath et al., 2012; França et al., 2020) and creates far-reaching effects on forest ecosystems (Foden et al., 2017; Cimatti et al., 2021). Forest ecosystems are sensitive to the climate in several ways, displaying a range of responses to the changing climate conditions. It was argued by Condon & Maxwell (2020) that climate change alters species distributions in the forest ecosystems. When climate behave in a detrimental way to normal growth of the forest population, it negatively affects them. As temperatures rise, as was reported by (Garcia et al., 2014; Giardinaet al., 2018), some species are very likely to find their existing nests and habitats detrimental and unsuitable and as a result these species usually attempt to shift their range toward cooler areas, such as higher altitudes. Such shifts can change and even disrupt the existing ecosystem harmony and lead to changes in biodiversity. Kale et al. (2016), Krishnan et al. (2020) reported that in the Western Himalayas of India, certain alpine plant species are retreating to higher altitudes due to increasing temperatures, altering the composition of the local ecosystems.

Another significant aspect of the linkages between climate change and forest ecosystem has been identified by Kosanic et al. (2020); these authors have reported that climate change has a significant impact on the growth rate and structure of forests. In the same line of discussion, a range of authors (for example, Kumar, Singh & Kalra, 2018; Lele, Joshi & Agrawal, 2008; Das et al., 2013; Ravindranath et al., 2012) have found that changes in temperature and precipitation patterns can hugely affect the rate at which trees grow. Prolonged periods of drought and high temperatures and the resultant heat have a huge influence in hindering the growth of forest population or even cause tree mortality (Lele, Joshi & Agrawal, 2008; Das et al., 2013), thereby affecting the overall forest structure (Kumar, Singh & Kalra, 2018). A range of studies associated with the highlands in India (initiated by several authors, including Rao et al., 2016; Ravindranath et al., 2018) have shown that certain tree species' growth rates are declining due to increasing temperatures and changing rainfall patterns.

3.3 Impacts of Climate Change on Forest Composition and Structure

Climate change is exerting a transformative influence on forest ecosystems (Gopalakrishnan et al., 2011; Giri et al., 2019; Srinivasulu, Srinivasulu & Srinivasulu, 2021; Ramachandra & Bharath, 2020), and it has been reshaping their composition and structure in significant number of ways.

Studies conducted by Nadeau & Fuller (2015); McDowell (2018) found in their studies that climate change has been altering species distribution and causing range shifts. Rising temperatures and changing precipitation patterns can render certain habitats inhospitable for species adapted to specific climatic conditions (Meiyappan et al., 2017; Haughan et al., 2022; Choe & Thorne, 2017). As the climate change, the scenario poses significant threats to these species because they are not used to the new and changed type of climate. As a result, these species usually and quite often look for a scope to migrate to cooler regions (Choe & Thorne, 2017), higher altitudes or latitudes (Corlett & Westcott, 2013), or experience population declines (Gopalakrishnan et al., 2011; Carroll et al., 2015) because they find it harsh to sustain in the changed climate. Hansen et al. (2013); Laube et al. (2013) found in their research that climate change affects the forest composition and structure in that it affects the mortality patterns and growth of trees. Similarly, other studies (such as Brosch, 2021; Pearce-Higgins et al., 2015; Haughan et al., 2022; Choe & Thorne, 2017) opined that climate change is impacting the growth and mortality patterns of trees, which in turn affects forest structure (Pearce-Higgins et al., 2015). Changes in temperature (Galbreath, Charles & Oczkowski, 2016), precipitation (Brosch, 2021), and the frequency of extreme weather events, such as droughts or cyclones can stress trees, and these occurrences can potentially slow down their growth rates or even these can cause increased mortality (Haughan et al., 2022). As individual species react to changing conditions (Maracchi, Sirotenko & Bindi, 2005; Neumann et al., 2017), there can be a cascading effect on the larger ecosystem. For example, it was revealed in the study by Ross (2018) that in the Eastern Himalayas, a varied level of changes in flowering times, which has happened because of warmer temperatures, has impacted pollinators, such as bees and butterflies. These species rely on these flowers for nectar. When such mismatch in phenology happens, it can potentially affect pollination success, and can lead to potential declines in plant diversity.

3.4 Impacts of Climate Change on Forest Processes

Climate change can significantly affect the forest processes.

Tei & Sugimoto (2018), Haughan et al. (2022) revealed that climate change significantly affects water availability and hydrological cycles within forest ecosystems. Forests play a crucial role because it regulates the water cycles; they help capture (Das & Behera, 2013), store (Jorgenson et al., 2019), and release water, these also influence local and regional precipitation. However, when there are changes in temperature and precipitation patterns, these can potentially disrupt these processes. This has been identified by Wani et al. (2012), who have revealed that in the Western Ghats, prolonged periods of drought and increased evapotranspiration because of rising temperatures have potentially affected water availability, and this has potentially changed the region's unique forest ecosystems. The consequent water stress can influence tree growth, survival, and reproduction, impacting overall forest health and biodiversity.

Many studies, such as Zhang et al. (2017), Wagner et al. (2014), have found that climate change has significant implications for carbon sequestration and storage. Upgupta et al. (2018) added to this discussion concerning the impact of climate change in carbon storage. The authors have implied that forests are vital carbon sinks, their contribution is that they capture and stores carbon dioxide from the atmosphere (Fahey et al., 2017; Choe & Thorne, 2017). However, Haughan et al. (2022) argued that climate change can significantly affect the capacity of forests to capture carbon di oxide from the atmosphere. The reason is that a rising temperatures and changing precipitation (Ravindranath et al., 2012; Carroll et al., 2015) can impact tree growth rates, and increased frequency of wildfires can release stored carbon back into the atmosphere. For example, in the central Indian forests, studies (Kaur, R., & Pandey, 2021; Kumar et al., 2020) have shown that increasing temperatures and changing rainfall patterns are impacting tree growth rates, potentially affecting the forests' capacity for carbon sequestration.

An important impact of climate change on the forest process is that it influences the cycling process of nutrient and the functioning of the ecosystems. It was found in a range of studies (for example, Gorelick et al., 2017; Hamann et al., 2015; Liang et al., 2018) that climate change influences nutrient cycling and ecosystem functioning. Similarly, Loarie et al. (2009), Milanesi et al. (2017)

found that when there are changes in temperature and moisture conditions, these affect soil microbial activity and the breakdown of organic factors that are essential for soil quality. In addition to the above discussion, a study conducted by Palchoudhuri, Roy & Srivastava (2015) argued that the changes in species composition and distribution, which is caused by climate change, have significant influences on litter fall patterns and nutrient inputs to the soil. In the Himalayan region, warming temperatures have affected the timing and rate of leaf litter decomposition, and this scenario has changed the nutrient cycling, which eventually altered tree health and productivity.

3.5 Impacts of Climate Change on Forest Disturbances

Climate change is a key driver of various forest disturbances, including wildfires, pest and disease outbreaks, and the effects of extreme weather events (Padalia et al., 2019; García Molinos et al., 2019). Each of these disturbances can have profound implications for the health, structure, and functioning of forest ecosystems.

A potential number of studies, including those of Greenwood et al. (2017); Heikkinen et al. (2020); Lewis, Edwards & Galbraith (2015) found in their studies that climate change is associated with an increased frequency and intensity of wildfires. This means there is a positive correlation between climate change and the frequencies of wildfire: more extreme climate conditions, more wildfires. What is more is that earlier snowmelt (Mishra, 2019) and longer dry seasons (Padalia et al., 2019) can lengthen fire seasons. In India, forest fires are a significant concern, particularly in the dry deciduous forests. An example related to the impact of climate change on the rising intensity of wildfires can be provided from the study of Vijaywargiya & Nidamanuri (2022) who revealed that the Bandipur Tiger Reserve in Karnataka experienced a severe wildfire in 2019, and this incidence was attributed to unusually dry conditions and heatwaves. These indicate the broader climate change patterns.

Harvey et al. (2019); García Molinos et al. (2019); Haughan et al. (2022) found that the expansion of pest and disease outbreaks is another disturbance, which is associated with climate change. García Molinos et al. (2019) argued that warmer temperatures can enhance the survival and reproduction rates of a range of pests and pathogens, and these can also extend their geographic ranges. In the Himalayan region in India, for example, pine forests have seen an increase in pest infestations (Kumar et al., 2020), such as the pine wood nematode, associated with warmer winters and changing precipitation patterns. These infestations can lead to widespread tree mortality, and these can also negatively affect forest health and biodiversity.

A good number of studies, such as Gopalakrishnan et al. (2011); Gonzalez (2001); FuentesCastillo, Hernández & Pliscoff (2020), have implied that extreme weather events (for example: cyclones, droughts, and floods) driven by climate change, can have dramatic effects on forest ecosystems. These naturally devastating occurrences and events can cause direct physical damage to forests. The authors (Gopalakrishnan et al., 2011; Fuentes-Castillo, Hernández & Pliscoff, 2020) have further stated that these devastating events create conditions (fires and pest outbreaks) that hampers the harmony of forest ecosystems. The mangrove forests of the Sundarbans in West Bengal of India are particularly vulnerable to cyclones, and these incidences of extreme cyclones have become more frequent in recent years. Cyclone Amphan in 2020 caused significant damage to these mangrove forests, impacting local communities and wildlife dependent on these ecosystems (Bhavithra & Sannasiraj, 2022).

3.6 Impact of CO2 emission on forest ecosystem

A study conducted by Arafeh-Dalmau et al. (2021) found that CO_2 emits from the burning of fossil fuels such as coal, oil, and gas, along with deforestation, and soil erosion. According to Statista (2023), global CO2 emissions from carbon emission were 19.5 billion metric tons, 25.5 billion metric tons, and 37.49 billion metric tons respectively in 1980, 2000, and 2022. These emissions continued to increase although there are significant efforts from countries around the world to reduce and control the emission (Shan et al., 2020; Fontaras et al., 2017; Feng et al., 2015).

In the same line of discussion, Li et al. (2018) reported that the increase in CO2 emissions affects the global carbon cycle. This is an important aspect because forests, oceans, and other natural systems act as carbon sinks, which absorbs a significant amount of CO2.However, a good number of studies (such as Shan et al., 2020; Fontaras et al., 2017; Begum et al., 2015; Fontaras et al., 2017) warned that the increasing and uncontrolled nature of CO2 emissions has become highly detrimental to the ability of forest to absorb carbons.

Studies conducted by Allen et al. (2010); Bennett et al. (2015); Arafeh-Dalmau et al. (2021) argued that an increasing level of CO2 emissions potentially have both direct and indirect effects on the forest ecosystems. While some trees usually grow faster due to a process called CO2 fertilization

(Brando et al., 2014), changes in climate patterns can influence the distribution and composition of forests (Carnicer et al., 2011; Chen, Wang & Inouye, 2017). The reason is that an increased CO2 emission increases vulnerability to pests, diseases, and fires, and disrupts the balance of these complex ecosystems (Chitale et al., 2014). Therefore, to develop a critical understanding of the impacts of CO2 emissions on forest ecosystems is crucial to develop sustainable strategies for forest management.

Several studies, such as Fang et al. (2018); Beland et al. (2019), found that plants play an invaluable role in regulating the carbon cycle of our planet. They act like carbon sinks; this role is crucial because they absorb more carbon dioxide from the atmosphere than they release. This function is incredibly important (Anderegg et al., 2015) since it helps in mitigating the impact of human-induced CO2 emissions. The role of forests as carbon sinks becomes even more evident when the studies (Sahana, Ahmed & Sajjad, 2016; Chen et al., 2019; Roy et al., 2015) are reviewed and analysed. These studies have reported that India had over 24% of its land area covered by forests in 2019 (Sahana, Ahmed & Sajjad, 2016; Chen et al., 2019; Roy et al., 2015). These forests include a varied number of species, ranging from the evergreen tropical forests in Kerala (Sahana, Ahmed & Sajjad, 2016), the deciduous Sal forests in Madhya Pradesh (Chen et al., 2019), to the coniferous forests in the Himalayas (Roy et al., 2015). Each of these forests sequesters carbon, helping to offset India's CO2 emissions.

To assess the role of forests in absorbing carbon, further studies were conducted. Bhardwaj et al. (2022); Islam (2019) found that the Sundarbans, the world's largest mangrove forest situated in the delta region of West Bengal of India, is a stellar example of a carbon sink. Mangroves are particularly effective at absorbing carbon (Islam, 2019). They store three to five times more carbon per equivalent area than tropical forests (Kosanic et al., 2019, Bhardwaj et al., 20212), while the majority of this carbon is stored in the soil. However, many authors (Sahana, Ahmed & Sajjad, 2016; Chen et al., 2019; Roy et al., 2015) have warned that the ability and capacity of forests to act as carbon sinks is not infinite and can be affected when there are deforestation, forest degradation, and changes in forest health. Therefore, efforts to reduce CO2 emissions must go hand in hand with efforts to conserve and sustainably manage our forests.

There is an intricate correlation between CO2 emissions and forest ecosystems for a wide number of reasons. Van Der Werf et al. (2017), Schulz et al. (2016) found that when there are excessive

CO_2 on the atmosphere, it accelerates tree growth rates, and this process is known as CO_2 fertilization. More CO_2 in the air can lead to increased photosynthesis (Buchholz et al., 2016), which can promote tree growth and improve efficiency of the use of water in forests. This process is important in areas, such as the Western Ghats and the Eastern Himalayas in India. In this region, vast expanses of forest potentially absorb significant amounts of CO_2 (Kanade & John, 2018; Bhutia et al., 2019).

However, this positive effect can be counterbalanced by other factors. For example, in many parts of India, higher temperatures and changing rainfall patterns—both consequences of increased CO_2 emissions and climate change—can lead to stress in forest ecosystems (Lovelock et al., 2017; Waheed et al., 2018). When there are prolonged dry periods, these can make forests more susceptible to pests and diseases (Schulz et al., 2016), as well as increasing the risk of forest fires (Waheed et al., 2018). For example, in Bandipur National Park in the state of Karnataka, changing climate patterns have been associated with an increase in forest fires (Verma et al., 2017). This incident has disrupted the forest ecosystem because it has released significant amounts of stored carbon back into the atmosphere (Ramachandra, Bharath & Gupta, 2018).

A number of studies (Dash et al., 2011; França et al., 2020; García Molinos et al., 2019) have revealed that elevated levels CO_2 in the atmosphere can significantly affect species composition and distribution within forest ecosystems. França et al. (2020) rationalized this event implying that some plant species may be more responsive to high CO_2 concentrations, and it leads to a potential shift in species dominance, which ultimately affects the overall ecosystem structure. As a result, some species may experience enhanced growth rates, while others may not benefit as much or even be negatively affected. A study conducted by Chave et al. (2008) found that increased CO_2 could favor fast-growing species over slow-growing ones in the India's tropical forests. As a result, it can potentially affect the species composition of the forests. Additionally, Smith-Martin et al. (2022) warned that climate change-induced shifts in temperature and precipitation patterns, triggered by increased CO_2 emissions, could affect the geographical range of certain species, which has the potentials in leading to changes in their distribution.

In their studies Gopalakrishnan et al. (2011); Heikkinen et al. (2020) found that increased CO_2 emissions can also affect plant-animal interactions and trophic dynamics within forest ecosystems. This happens mainly because elevated CO_2 can alter the nutritional quality of plant tissues

(Heikkinen et al., 2020), which in turn affects herbivores and their predators (Kumar, Singh & Kalra, 2018). When there are changes in plant species composition and growth patterns, it can significantly impact herbivores and their predator; it can potentially result in ripple effects throughout the food chain (Gopalakrishnan et al., 2011; Loarie et al., 2009).

Concerning the cases in India, as reported in the study by Sundararaj (2014), in India's teak forests, pest attacks are a significant concern. As CO2 levels rise, the interaction between teak trees and their pests could shift, with implications for forest health and management practices. Another relevant study conducted by Murugan et al. (2020) concerning the Nilgiri Biosphere Reserve, located in southern India, has revealed that high levels of CO2 have contributed to the growth of invasive species such as Eucalyptus and Acacia. Unfortunately, these species can harbour harmful pests like the blue gum chalcid wasp. These are species which have caused extensive damage to native eucalyptus trees, negatively affecting the overall well-being of the forest ecosystem (Murugan et al., 2020).

The combined effects of elevated CO2 on biotic and abiotic stress factors can increase the vulnerability of forest ecosystems to disturbances, and it can result in a range of natural disasters such as wildfires, storms, and landslides (Rao et al., 2016). Changes in species composition and stress tolerance can alter the dynamics of these disturbance events, affecting the overall resilience of the forest ecosystem.

3.7 Impact of increased agriculture on the forest ecosystem

Tuomisto et al. (2012) defined agriculture as the systematic and controlled use of living organisms (plants, animals, fungi, and microorganisms) and the environment to produce food, fibre, medicinal plants, fuels, and other products (see Chae & An, 2018), which are often considered beneficial for the human beings. On the other hand, Clark & Tilman (2017) have defined the term forest ecosystems, saying that these are complex webs of organisms, which often include trees, plants, animals, insects, fungi, and microbes that interact with each other. They encompass a vast array of habitats (Gomiero, Pimentel & Paoletti, 2011), from tropical rainforests to temperate woodlands, and play a vital role in the global environment by their contribution through serving as carbon sinks (Clay, 2013), water purifiers (Poore & Nemecek, 2018), habitat for biodiversity (Thuy et al., 2012), and a source of livelihood for many communities around the world (Clark & Tilman, 2017).

Over centuries, human societies have cleared vast areas of forest to make way for agriculture (Jaworski & Hilszczański, 2013; Smith, 2012), and these practices have significantly affected the landscapes and impacted the biodiversity and climate of the earth. In contrast to the negative relationship assessed on the above, Overbeck et al. (2015) found some positive implications, reporting that healthy forest ecosystems can significantly benefit agriculture by providing essential services. Forests regulate water flows, maintaining water quality and availability for irrigation. Manu authors have also supported this stance, studies have found that agriculture often foster soil health (Tawalbeh 2021), provide habitat for pollinators and natural predators of agricultural pests (Balaram, 2019), and help mitigate climate change by sequestering carbon dioxide (Savci, 2012).

Many studies (Tilman et al., 2011; Hernandez et al., 2014; Ripple et al., 2014) have recommended and emphasized the importance of studying the impact of agriculture and forest ecosystems. De Vries & de Boer (2010) opined that understanding the importance of studying the impact of agriculture on forest ecosystems plays a significant role in the sustainability of both our food systems and our environment, and thus has implications for conservation, policy-making, and future agricultural practices. Ripple et al. (2014) also revealed that forests are hotspots of biodiversity that host most of the terrestrial plant and animal species. Deforestation and forest degradation due to agriculture can lead to the loss of habitats and fragmentation (Tilman et al., 2011), which ultimately threatens the survival of numerous species (Hernandez et al., 2014). By understanding this impact, we can devise strategies to mitigate biodiversity loss.

Balthazar et al. (2015) opined that forests play a crucial role in climate change mitigation by acting as carbon sinks, absorbing large amounts of carbon dioxide. Lawler et al. (2014) added that when forests are cleared for agriculture, not only does it hamper the carbon capacity of the forests, but stored carbon is also released back into the atmosphere. As a result, this contributes to global warming. Evaluating this impact can contribute to the development of better land-use strategies and climate change mitigation efforts. Edwards et al. (2014); Balthazar et al. (2015) added that forests maintain soil health by enriching it with organic matter and preventing erosion with their root systems. When forests are replaced with agricultural land, soil health can deteriorate (Li et al., 2018), and this results in an increase of soil erosion. Studying these impacts can help to develop agricultural practices that maintain or improve soil health.

3.8 Expansion of agricultural land and deforestation

The relationship between agricultural expansion and deforestation is well documented in literature. With growing population pressure and increasing demand for food, there has been a worldwide trend of agricultural land expanding into forested areas, resulting in significant deforestation (Nannipieri, Greco & Ceccanti, 2017; Rey Benayas & Bullock, 2012; Lungarska & Chakir, 2018). The interplay between agricultural expansion and deforestation has been a significant research focus. For instance, studies like Lungarska & Chakir (2018); Viglizzo et al., (2011) have shown how the demand for commodities like palm oil and soybeans has driven large-scale deforestation in Indonesia and Brazil, respectively. In Africa, Bloomfield, McIntosh & Lambin (2020) document how small-scale subsistence farming often leads to forest fragmentation. Work by Rey Benayas & Bullock (2012) underscores the impact of livestock farming on deforestation, particularly in Latin America, owing to the growing demand for meat. These studies highlight the global scale of the issue, stressing the need for sustainable land use policies and practices that can balance the demands of agriculture and forest conservation.

In India, this issue is pronounced, given the country's large population and the crucial role agriculture plays in its economy. Research studies by a number of authors (Bhuyan et al., 2019; Viswanathan & Bhowmik, 2016) have shown that agricultural activities have led to substantial forest cover loss, particularly in states such as Madhya Pradesh, Chhattisgarh, and Odisha. Scholars like Bhuyan et al. (2019) suggest that shifting cultivation, where farmers move from one piece of land to another to maintain soil fertility, practiced by indigenous communities in northeastern states like Assam, Meghalaya, and Nagaland, has contributed to forest loss. However, it's worth noting that this practice can be sustainable when population density is low and sufficient fallow periods are allowed. On the other hand, a study by Viswanathan & Bhowmik (2016) highlights the replacement of diverse natural forests with monoculture plantations, such as rubber in Tripura and oil palm in Andhra Pradesh, as another form of deforestation driven by marketoriented agriculture.

Intensive agricultural practices often involve the use of high levels of inputs such as fertilizers, pesticides, and water to maximize crop yields. Globally, there is ample research evidence on the environmental implications of such practices. In a review, Mori Lertzman & Gustafsson (2017); Chae & An (2018) demonstrated that intensive agriculture, while increasing food production, has led to significant environmental degradation, including soil erosion, water pollution from fertilizer runoff, and loss of biodiversity due to monoculture plantings. Similarly, De Beenhouwer, Aerts & Honnay (2013) showed how synthetic nitrogen fertilizer use in intensive agriculture contributes significantly to nitrous oxide emissions, a potent greenhouse gas. Furthermore, Geneletti (2013); Tuomisto et al. (2012) documented the detrimental effects of pesticide use on non-target organisms, pollinators, and biodiversity.

In the Indian context, Rahman (2015) highlighted the negative environmental implications of the Green Revolution's intensive practices, particularly in Punjab and Haryana. Excessive use of water for paddy and wheat cultivation has led to significant groundwater depletion. High fertilizer use has also led to soil degradation and water pollution. A case study by Bhuyan (2009) in the Indo Gangetic plains showed how continuous rice-wheat cropping systems have led to declining soil fertility and productivity, due to intensive agricultural practices. The above studies underscore the need to balance agricultural productivity with environmental sustainability, underlining the importance of adopting sustainable agricultural practices. Research by Reddy et al. (2016) indicates extensive deforestation in states like Madhya Pradesh, Chhattisgarh, and Odisha due to the conversion of forests into agricultural lands, leading to the loss of forest cover and subsequent environmental implications. This conversion disrupts ecosystems, affects the availability of forest goods and services (Reddy, 2017), and exacerbates climate change impacts through carbon emissions from deforestation. Effective land-use planning, policies, and sustainable farming practices are thus vital to mitigate these effects.

The expansion of agricultural lands often results in the fragmentation of forest habitats, which is detrimental to biodiversity. Brockerhoff et al. (2017); Warren-Thomas, Dolman & Edwards (2015) underlines that habitat fragmentation due to agricultural expansion can isolate wildlife populations, disrupt animal movements, and ultimately lead to local and global extinctions. In the Indian context, the Western Ghats, a biodiversity hotspot, has experienced significant habitat fragmentation due to agricultural encroachments (TV, Setturu, & Chandran, 2016). Similarly, the Northeastern states have seen forest fragmentation due to shifting cultivation and commercial plantation crops, affecting wildlife corridors essential for species like elephants and tigers (Kong, Zhou & Jiao, 2021). The loss of biodiversity due to such fragmentation has severe implications, affecting ecosystem services, including pollination, pest control, and disease regulation, which are vital for agriculture itself.

Soil degradation and erosion are other significant impacts of agricultural activities. Van Vliet ety al. (2012); Overbeck et al. (2015) points out that intensive agricultural practices, particularly monoculture and overuse of synthetic fertilizers, can lead to soil degradation and loss of soil fertility on a global scale. In India, the Green Revolution's intensive practices have resulted in soil degradation in many areas (Jaworski & Hilszczański, 2013; Smith, 2012).

Agriculture, especially irrigated agriculture, can alter local and regional hydrological cycles, with potential implications for forest water availability (Lawler et al., 2014; Li et al., 2018). Overextraction of groundwater for irrigation can lower water tables, affecting the availability of water for forest ecosystems, while altering surface water flows can impact wetland and riparian forests (Lindner et al., 2010; Balthazar et al., 2015). In India, examples of such impacts are evident. Negi et al. (2019) found that extensive groundwater extraction for agriculture in semi-arid regions of Rajasthan has lowered water tables, affecting the health of adjacent forest ecosystems. Similarly, Jaworski & Hilszczański (2013) documented reduced water availability for forests in the Western Ghats due to the diversion of surface water for irrigation. These examples emphasize the need for integrated water management that considers the needs of both agriculture and forests.

3.9 Conflicts and Trade-Offs between Agriculture and Forest Conservation

The growing human population has increased demands for food and land, leading to heightened competition between agriculture and forest conservation globally. Redpath et al. (2013); Scheba & Rakotonarivo (2016); Keith et al. (2017) highlights the inherent challenges in managing this competition, as both sectors provide crucial ecosystem services yet have divergent and often conflicting objectives. Expanding agricultural land often leads to deforestation ((Setälä et al., 2014; Kovács et al., 2015), impacting biodiversity, disrupting ecological functions, and reducing carbon sequestration, among other services provided by forests (Setälä et al., 2014; Kovács et al., 2015). In India, the conflict is increasingly apparent. Rodrigíguez et al. (2006) indicate that the agricultural expansion in the Thar Desert has encroached on protected forest areas, thus creating conservation dilemmas. Nesheim et al. (2014) provide an example from the Western Ghats, where the expansion of tea plantations has resulted in significant forest loss, despite the recognition of the region as a global biodiversity hotspot. These examples underscore the need for harmonious land-use planning and policy interventions.

Balancing the imperatives of boosting agricultural productivity and pursuing sustainable land management represents a critical challenge, especially in the context of climate change and biodiversity loss (King et al., 2015; Bradford & D'Amato, 2012; Nesheim et al., 2014; Woodford et al., 2017). Agricultural intensification, although proposed as a solution to spare forests, can have its detrimental environmental impacts, including soil degradation, water pollution, and loss of biodiversity (Mutoko, Hein & Shisanya, 2015; Kim & Arnhold, 2018; Sanon et al., 2012). India's struggle with this balance is evident. Bustamante et al. (2014) illustrate how the Green Revolution's intensive practices have resulted in significant soil and water degradation, undermining the longterm sustainability of agricultural lands. Similarly, Turkelboom et al. (2018) emphasize that, while the conversion of forest land into agriculture in North-East India has increased short-term crop yields, it has led to significant soil erosion and loss of forest biodiversity.

Despite the conflicts, there exist potential synergies between agriculture and forests, which can offer win-win solutions. Agroforestry, for instance, can improve agricultural productivity, enhance biodiversity, and contribute to carbon sequestration (Hermoso et al., 2018; Sandström et al., 2011; Wong & van der Heijden, 2019). Similarly, sustainable farming practices like organic farming and conservation agriculture can enhance soil health, reduce water pollution, and contribute to biodiversity conservation (Bustamante et al., 2014; Wong & van der Heijden, 2019). In Indian cases, several initiatives are exploring these synergies. Ariza-Montobbio & Lele (2010) discuss the successful integration of farming with forest conservation in Auroville, Tamil Nadu, illustrating that a combination of agroforestry and organic farming can enhance biodiversity while ensuring agricultural productivity. Similarly, Hutton et al. (2018) document how community forestry initiatives in Rajasthan have successfully reconciled the need for firewood (a major agricultural by-product) with forest conservation goals. These examples underline that a nuanced understanding of local ecological and social contexts is critical to design and implement such win win solutions.

3.10 Impact of increased urbanization on the forest ecosystem

Theodorou (2022) defined urbanization, implying that it refers to the increasing number of people that live in urban areas. It predominantly happens as a result of people's migration from rural areas to urban settings in search of better livelihoods, education, healthcare, and other amenities (Cyril, Oldroyd & Renzaho, 2013). The process involves the growth of existing cities (city expansion) and the rise of new urban areas. It is marked by an escalation in the construction of infrastructure such as buildings, roads, and other civic amenities (Jaysawal & Saha, 2014). Additionally, urbanization has transformative effects on society, the economy, and the environment, making it a critical area of focus for policy, planning, and scientific study.

Many studies (PTI, 2022; Urban Governance Model of Maharastra, 2023; Islam, Ali & Mithun, 2021) have reported that in recent decades, India has witnessed a significant surge in urbanization. According to PTI (2022), referring to the United Nations' World Urbanization Prospects report, by 2030, India's urban population will reach 590 million, which is a considerable increase from 461 million in 2020. This dramatic upsurge is attributed to various factors such as industrialization, globalization, and the expansion of service sectors.

As per the data released by the Indian government, the urbanization rate has steadily risen from 27.8% in 2001 to 31.2% in 2011, as stated in the Census of India (Urban Governance Model of Maharastra, 2023). The pace of this urban growth has varied across different states, with some exhibiting faster urbanization rates than others. For instance, Goa and Mizoram are the most urbanized states, with over 70% of their population living in urban areas (Islam, Ali & Mithun, 2021), followed by Tamil Nadu and Kerala. However, larger states like Uttar Pradesh, Bihar, and Rajasthan are still predominantly rural (Shastri et al., 2015). On the other hand, as reported by Maparu & Mazumder (2017), metropolitan cities such as Delhi, Mumbai, and Kolkata have expanded exponentially in terms of both population and geographical area. Simultaneously, several smaller cities and towns are also experiencing rapid urban growth. For example, Gurugram in Haryana, once a small town, is now a bustling city and a major hub for the IT and financial sector (Franco, Mandla & Rao, 2017).

A study by Chandra, Shiva & Nanjundaswamy (2018) found that the expansion of urban areas often comes with infrastructure development, which includes constructing buildings, roads, and facilities, thereby modifying the landscape drastically. This urban sprawl has considerable consequences on the environment, one of the most affected being the forest ecosystem. However, Pandey & Seto (2015); Paul et al. (2018) warned that the growth in urbanization has also led to several challenges, such as increased pressure on infrastructure, the growth of slums, and the destruction of natural habitats, including forests, which are critical for maintaining biodiversity and ecological balance.

Several drivers of urbanization can profoundly impact forest ecosystems globally and in India. These drivers include population growth, economic development, industrialization, and policy decisions among others (Fenoglio, Rossetti & Videla, 2020; Su et al., 2012).

Urbanization globally is driven by an array of interconnected factors. Su et al. (2012); Delphin et al. (2016); Bathla (2022) identify economic development as a significant driver. Population growth, as discussed by Bai et al. (2019), Freeman et al., (2019), is another critical driver of urbanization. Government policies also significantly influence urbanization patterns (Liu et al., 2019; Escobedo et al., 2019). For example, urban planning and land-use policies can either mitigate or exacerbate the impacts of urbanization on forest ecosystems (Escobedo et al., 2019). Policies that promote urban sprawl often lead to more significant negative impacts on forests, while those that encourage compact urban development can help to minimize these impacts (Singh et al., 2014; Giweta, 2020). Likewise, government policies, including those related to land use and economic development, have also played a significant role in driving urbanization in India. For instance, special economic zones and industrial corridors have been established to promote economic growth, often leading to rapid urbanization in these areas (Zope, Eldho & Jothiprakash, 2015; Maparu & Mazumder, 2017; Chimankar, 2016).Technology and globalization have been identified by Niu et al. (2012); Felipe-Lucia et al., (2018) as additional drivers of urbanization.

Habitat loss and fragmentation are two crucial ecological impacts of urbanization. Delphin et al. (2016); De Frenne et al., (2021) explained that habitat loss occurs when land is converted for other uses, such as urban development, leading to a complete change in land cover type and the disappearance of the original habitat. The transformation of forests into urban areas, industrial sites, and agricultural lands are classic examples of habitat loss. Conversely, habitat fragmentation, as described by Zhang et al. (2012), Negi et al., (2019), is a process whereby a large, continuous area of habitat is both reduced in area and divided into two or more fragments. These fragments are isolated from each other by a matrix of habitats unlike the original. Urbanization is a leading cause of fragmentation as new developments carve up forests and other natural habitats, creating isolated patches.

These processes have significant impacts on forest ecosystems. Wang et al. (2019); Das et al., (2019) emphasized that both habitat loss and fragmentation could lead to a decrease in biodiversity. As habitats become fragmented, wildlife populations get isolated, leading to decreased genetic diversity, an increase in inbreeding, and heightened risk of local extinctions. Su et al. (2022) highlighted that these processes also disrupt ecological functions. They interfere with the movement and dispersal of species, disrupt predator-prey relationships, and alter abiotic conditions such as temperature and moisture.

Additionally, Gu et al. (2012); Sannigrahi et al., (2020) elucidated that fragmentation often creates 'edge effects,' where conditions at the edge of a fragment differ markedly from the interior, affecting species distribution and community structure. Further, habitat loss and fragmentation can undermine the provision of ecosystem services, such as water purification, carbon sequestration, and provision of timber and non-timber forest products, having significant implications for human wellbeing (Wan et al., 2015).

In the context of India, the effects of habitat loss and fragmentation due to urbanization are evident. For instance, Sharma et al. (2020) detailed that the Western Ghats, one of the world's biodiversity hotspots, has experienced significant habitat loss and fragmentation due to urban expansion, leading to the decline of several endemic and endangered species. Nagendra et al. (2013) illustrated that Bangalore's rapid urban growth has led to the loss of over 78% of its vegetation cover in just four decades, resulting in significant habitat loss and fragmentation and impacting local biodiversity.

Similarly, Das & Das (2019) pointed out the transformation of the Kolkata Metropolitan Area, where urban expansion has resulted in considerable loss and fragmentation of the East Kolkata Wetlands. These wetlands, which provide crucial habitat for numerous species and essential ecosystem services, are under severe threat due to urban encroachment. Therefore, strategies to balance urban development and conservation needs in India's context are of utmost importance.

Urban development often leads to changes in biodiversity and species composition in forest ecosystems. According to Liu et al. (2019), this is primarily driven by habitat loss and fragmentation, leading to isolation of wildlife populations and disruption of species movement and dispersal. As a result, some species, particularly those with large home ranges and specialist species, may decline or disappear altogether due to lack of suitable habitat or inability to adapt to the altered conditions (García-Nieto et al., 2018). Conversely, other species, such as those adaptable to human-dominated landscapes or invasive species, may proliferate (Peng et al., 2017).

This reshuffling of species composition can impact ecosystem structure and function and can have cascading effects on the food web and ecological processes.

3.11 Social and Economic Consequences of Urbanization on Forest Ecosystems

Urbanization impacts forest ecosystems not just ecologically (Delphin et al., 2016; Bai et al., 2019), but also socially and economically (Cao et al., 2021; Gu et al., 2022; Long et al., 2014). Various studies have highlighted these changes, including shifts in human-wildlife interactions, alterations in cultural and recreational values of forests, and impacts on forest-based livelihoods and economic benefits.

Urban expansion into forested areas can precipitate significant changes in human-wildlife interactions. Delphin et al. (2016); Yu et al. (2021) argue that as urban areas encroach upon wildlife habitats, encounters between humans and wildlife increase, sometimes leading to conflict. This conflict often carries severe implications for both wildlife conservation and human safety. On the other hand, Bai et al. (2019) posit that urban forests can facilitate positive human-wildlife interactions by serving as sanctuaries for certain species, thereby providing urban dwellers with opportunities for wildlife observation and appreciation, thus fostering pro-conservation attitudes (Gu et al., 2022; Xiao et al., 2020).

Urban forests and green spaces hold significant cultural and recreational values for city dwellers. Cao et al. (2021); Aznar-Sánchez et al. (2018) argue that urban forests serve as important sites for outdoor recreation, contributing to improved mental and physical health among urban populations. However, Gu et al. (2022) caution that the increased use of forested areas for recreation can lead to degradation of these habitats if not properly managed. In the Indian context, cultural and recreational values of urban forests are substantial but often overlooked in urban planning (Irfaan, Jo & Mondal, 2016; Marshall et al., 2018).

The impact of urbanization on forest-based livelihoods and economic benefits can be profound. Zhou Tian & Jiang, et al. (2018); Escobedo et al. (2019); Peng et al. (2020) point out that while urbanization can create new economic opportunities, it can also disrupt traditional forest-based livelihoods by reducing access to forest resources and changing land-use patterns. This often affects the most vulnerable populations who rely on these resources for their subsistence and income. In India, the impacts of urbanization on forest-based livelihoods are also significant. For instance, Sudhira & Nagendra (2013); Das, Das & Pandey (2023) studied the impacts of urbanization on the Soligas, a forest-dependent indigenous community in southern India. Their findings revealed that urban expansion has led to a loss of access to forest resources, affecting the community's traditional livelihoods and causing socio-economic distress.

These complex interrelations highlight the need for a more integrated and sustainable approach to urban development that considers both ecological and socio-economic implications (Bassi et al., 2014; Irfaan, Jo & Mondal, 2016). As urban areas continue to expand, it becomes crucial to integrate urban planning with biodiversity conservation and social equity considerations.

The ever-increasing emphasis placed on the protection of natural resources and the promotion of environmentally responsible practices has made it more important than ever to have a solid understanding of the complex dynamics at play among the numerous elements that influence natural occurrences. As a consequence of this, the use of econometric models in the natural sciences, such as forestry and agriculture, has seen a surge in popularity (Negara et al., 2021). Some examples of these models include the Autoregressive Distributive Lag (ARDL) model, the Dynamic Ordinary Least Square (DOLS) model, and the Canonical Cointegrating Regression (CCR) model. Researchers are able to capture complicated linkages, estimate short-term and long-term impacts, and solve econometric concerns such as endogeneity and autocorrelation with the help of these models, which ultimately results in strong and dependable conclusions. (Shahbaz et al., 2015; Chandio et al., 2020) The purpose of this literature review is to provide a theoretical basis for the ARDL, DOLS, and CCR models, with an emphasis on their function and relevance in the study of natural science.

3.12 Data and Methodology

The study's fundamental purpose is to explore the impact of temperature anomaly, rainfall anomaly, per capita Co_2 emissions, agricultural land, and urbanization on forest loss in India. The study adopted a secondary annual time-series database from 1991-2019 using the ARDL method to test the nexus between the variables. To fulfil the objective of the current study, the datasets of the sort-out variables in the study are from World Development Indicator and Indiastat. There are five variables for analysis: forest loss is the dependent variable, and the independent variables are both the climatic and non-climatic variables. Climatic variables include temperature anomaly, rainfall anomaly, and Co_2 emissions. Non-climatic variables include agricultural land and urbanization. A detailed description of the variables is in Table below:

Variables	Symbol	Unit	Source
Forest Loss	FL	Percentage	Indiastat
Temperature Anomaly	TA	Celsius	World Bank
Rainfall anomaly	RA	Mm	World Bank
Per Capita CO2 emissions	CO2	Mt.tons	World Bank
Agriculture Land	AL	1000 Hectare	World Bank
Urbanization	URB	Number	World Bank

Table 3.1: Detail of variables

Pesaran developed the Auto-Regressive Distribution Lag Model (ARDL), and Shin (1998) and Pesaran et al. (2001) were used to capture the long-run cointegration association between dependent and independent variables. The benefits of the ARDL bounds test over the traditional cointegration technique are as follow (a) it is used when there is a mixed order of integration, (b) it incorporates both the short and long-run coefficients simultaneously; (c) it is perfectly fit for small sample size; (d) accommodating different lag length and also removed the autocorrelation problem in the dataset. In order to quantify the impact of climatic and non-climatic variables on forest loss in India, the current study uses an autoregressive distributed lag (ARDL) model.

The following steps are for study analysis. The first step is to determine whether the variables are stationary or not. To select the order to integrate study variables, the Augmented Dickey-Fuller (ADF) and Philips-Perron (PP) unit root tests (Philips and Perron, 1988) are done in this study. If the variable is integrated of order two, i.e., I(2), it will bring spurious results. After stationarity analysis, the second step of the study is to determine the lag length because F-test is more sensitive to the lag order of the variables. **.** In the last step, we estimate the autoregressive distributed lag bounds testing approach introduced by Pesaran et al. (2001) to capture the long and short-run linkages between study variables. The expression of the function is as follows:

$$FL = (TA, RA, CO_2, AL, URB) \qquad (1)$$

In equation (1), TA, RA, CO_2, AL, URB expressed temperature anomaly, rainfall anomaly, and per capita CO_2 emissions, which are considered climatic variables, whereas agricultural land and urbanization are non-climatic variables, respectively. In equation (1), t=1…N represents the time period. Equation (1) can be written as

$$FL_t = \beta_0 + \beta_1 TA_t + \beta_2 RA_t + \beta_3 CO2_t + \beta_4 AL_t + \beta_5 URB_t + \epsilon_t \tag{2}$$

The parameters β_0, β_1, β_2, β_3, β_4, $and \beta_5$ measure the long-run elasticities of economic growth concerning RI, EE, EU, IN, and POV, respectively. The calculated F-statistics are compared to the lower and upper-bound critical values. When the calculated F-statistics is below, the null hypothesis is not rejected; when the calculated F-statistics is greater, the null hypothesis is rejected, which shows evidence of a long-run relationship among the variables.

3.13 Auto-Regressive Distributed Lag (ARDL) Model

The Auto-Regressive Distributed Lag (ARDL) model is a widely utilized econometric technique in empirical investigations. The model, which was first introduced by Pesaran et al. (2001), has gained significant popularity due to its ability to effectively analyze short and long-term connections between relevant variables (Shahbaz et al., 2015; Negara et al., 2021). The methodology employed involves incorporating lagged values of both the dependent and independent variables as predictors, thereby facilitating a more comprehensive comprehension of the interplay between them. This approach has been expounded upon by scholars such as Innocent (2017) and Adegboyo (2020).

3.13.1 Applications in Forestry and Agriculture

Long-term and short-term interactions between variables in forestry and agriculture have been studied and quantified using the ARDL model, providing important insights for policy and practice. Chandio et al.'s (2020) study is illustrative; they used the ARDL model to investigate how climate change affects agricultural output in China. What they found was evidence of long-term cointegration between the variables, which is significant because it shows how much of an influence climate change is having on agricultural yields.

In a similar vein, Ghimire et al. (2021) analyzed the effect of climate change on forest area change in Bangladesh by using the ARDL model. The importance of climate change impacts on forest resources was further emphasized by their finding of a substantial short-run and long-run link between forest area and climatic variables.

The ARDL method was also used by Salakpi et al. (2022), although in a somewhat different setting, to investigate what factors influence cocoa output in Ghana. They showed that variables including farm size, labor availability, and price had substantial short- and long-term effects on cocoa production, highlighting the complexity of the factors that affect agricultural output.

In order to learn how institutional credit affects agricultural output in Ethiopia, Getachew & Assefa (2020) used the ARDL model. Their findings showed a favorable long-term correlation, highlighting the significance of banks to rural development. Meanwhile, Kargar Dehbidi & Tarazkar (2020) used the ARDL model to look at how agricultural water usage relates to economic development, and they found that there was a long-term, one-way causality between the two.

Using the ARDL model, Campos (2023) investigated how climate change has affected European coffee output and found strong long-run cointegration between climatic factors and coffee yields. Despite the diversity of settings and topics addressed by these studies, a similar thread emerges: the ARDL model is useful for illuminating both long- and short-term dynamics in agricultural and forestry contexts. These studies also highlight the need for caution when interpreting and applying the results and consequences of these linkages in policy and practice, since they are complicated and multidimensional.

In sum, the ARDL model has proven to be an invaluable tool in forestry and agriculture research, elucidating intricate relationships and driving informed decision-making. However, as with any model, the accurate interpretation of its findings is contingent upon an understanding of the model's underlying assumptions and limitations.

3.13.2 Strengths and Limitations

Due to its many useful features, the ARDL model is an effective resource for forestry and agriculture. As pointed out by Shahbaz et al. (2015), the model may be used whether the underlying regressors are I(0), I(1), or mutually cointegrated, demonstrating its adaptability. This is helpful because it eliminates the issue of false regression, which hampers efforts to discover genuine connections between variables.

The model's flexibility in representing both transitory and persistent associations between variables is another area of strength (Alsaleh & Abdul-Rahim, 2019). This is especially important in policy interventions in industries like agriculture and forestry, where the effects may be felt both now and in the future. Changes in forestry management or agricultural practices, for instance, may have short-term benefits but far-reaching effects on sustainability and output. By estimating how quickly a system returns to its long-run equilibrium following a shock, the ARDL model may provide important information on the robustness and adaptability of agricultural or forestry infrastructures (Wang et al., 2016; Osman et al., 2019).

However, despite its considerable advantages, the ARDL model has some limitations. Innocent (2017) points out that the model can lead to biased estimates when there is endogeneity among the regressors, a common scenario in social and economic data. Negara et al. (2021) echo this concern, stressing that while ARDL is a robust model, its reliability heavily depends on the careful handling of potential endogeneity issues.

3.14 Dynamic Ordinary Least Square (DOLS) Model

The genesis of the Dynamic Ordinary Least Square (DOLS) model lies in its emergence as a refined estimation technique within econometric literature to address shortcomings in traditional Ordinary Least Squares (OLS) estimation, particularly in the context of cointegrated systems (Merlin & Chen, 2021). The model, introduced by Stock and Watson in 1993, has since garnered significant attention due to its robustness and superior statistical properties.

In summary, the DOLS model evolved as a refinement of the traditional OLS model, offering solutions to common problems like endogeneity and increasing the efficiency and reliability of long-term estimates. Over time, it has proved its applicability across different fields, including natural sciences, gaining recognition for its robustness and accuracy.

At the heart of the Dynamic Ordinary Least Squares (DOLS) model lies a framework that builds on the standard OLS model but with an enhanced approach that offers solutions to address the potential bias and inconsistency issues often found in the traditional OLS model, especially in the context of cointegrated variables (Streimikiene & Kasperowicz, 2016). The fundamental assumption underpinning the DOLS model is that the variables under consideration are cointegrated, indicating a long-term, equilibrium relationship among them (Raihan, 2023). It further assumes that the errors from the regression are serially uncorrelated and normally distributed, ensuring the efficiency of estimators (Raihan et al., 2023).

Mathematically, the DOLS model estimates the following equation: $Yt = \alpha + \Sigma\beta iXi,t + \Sigma\ \theta i\Delta Xi,ti + \varepsilon t$, where Yt is the dependent variable, Xi,t represents the explanatory variables, ΔXi,t-i are the leads and lags of the changes in the explanatory variables, and εt is the error term (Jamil et al., 2022).

In conclusion, the DOLS model's theoretical framework eliminates possible endogeneity and yields unbiased and consistent long-run estimates by introducing leads and lags of the differences of the explanatory variables in the estimation process, predicated on the assumption of cointegration among variables.

3.14.1 Applications in Forestry and Agriculture

Continuing with the analysis of DOLS applications, the findings of these studies extend beyond their immediate contexts, providing important implications for the broader fields of forestry and agriculture. In the study by Raihan (2023a), the finding of forest cover acting as a major sink for CO_2 emissions underscores the environmental value of forests. This finding aligns with the broader scientific consensus that increasing forest cover is a key strategy to mitigate the impacts of climate change (Streimikiene & Kasperowicz, 2016).

The detrimental effects of climate change on agricultural production were recently studied by Raihan and Tuspekova (2022a), highlighting the need for adaptation and resilience-building initiatives in the agriculture sector. This is consistent with the claim made by Raihan et al. (2023) that new agricultural technology and climate-aware practises are required to keep production high in the face of a warming planet. The policy implications of Raihan's (2023b) finding of a positive link between agricultural commerce and food security are substantial. There has been a lot of talk about how free and fair international trade systems might help ensure food security throughout the world, and this study lends credence to that theory (Jamil et al., 2022).

The relevance of socioeconomic variables in increasing agricultural output is shown, finally, by the results of studies by Hafeez et al., (2020) and Waheed et al., (2018). Literature such as Lin & Benjamin (2018) and Ghazali & Ali (2019) bolster the argument that more money should be spent on agricultural infrastructure and human capital development to increase productivity and guarantee food security.

Together, these studies demonstrate the versatility of the DOLS model in providing robust insights into complex interrelationships within forestry and agricultural research, thereby reinforcing its relevance and applicability in these fields.

3.14.2 Strengths and Limitations

The Dynamic Ordinary Least Square (DOLS) model carries certain advantages and disadvantages that have become apparent through its application to forestry and agriculture as evidenced by the literature. The strengths are as follow:

Robustness: One of the main strengths of the DOLS model is its robustness in the presence of endogeneity, which is a common issue in forestry and agriculture studies. Raihan et al., (2023a) highlight that DOLS can produce unbiased and efficient estimates even when variables are endogenously determined.

Addressing Serial Correlation: DOLS effectively handles serial correlation in error terms, which can improve the reliability of estimates. Raihan et al., (2023b) demonstrate this aspect in their work.

Handling Co-integration: A key feature of the DOLS model is its ability to handle co-integration among variables. It's particularly useful when investigating long-term relationships among variables, an aspect central to several studies in agriculture and forestry (Raihan & Tuspekova, 2022b).

The limitations are as follows:

Complexity: The DOLS model, while statistically robust, is more complex and computationally intensive compared to other simpler models. This aspect could limit its usability for researchers with limited computational resources (Raihan & Tuspekova, 2022c).

Sensitivity to Specification: Raihan et al., (2022) noted that the DOLS model is sensitive to specification errors, meaning that incorrect model specification can lead to inaccurate results.

Overfitting Risk: Lastly, there's a risk of overfitting with the DOLS model, especially when the number of lags is not correctly specified. Overfitting can lead to the model capturing noise rather than the underlying relationship among variables (Raihan & Tuspekova, 2022d).

Overall, while the DOLS model has its strengths and is a powerful tool for analysis in forestry and agriculture, it must be used judiciously, considering its limitations and requirements for accurate specification and significant computational resources.

3.15 Canonical Cointegrating Regression (CCR) Model

The Canonical Cointegrating Regression (CCR) model serves as a sophisticated tool in econometric analysis, specifically in handling cointegrated time series data (Mohamed, 2021). Its inception and progression have been marked by significant contributions from various researchers. The CCR model's development was a response to the challenge of handling cointegration in nonstationary time series data. It came into prominence because of its unique approach to estimating long-run relationships without requiring pre-testing for unit roots or cointegration (Merlin & Chen, 2021).

Furthermore, Tripathy & Mishra (2021) and Mohamed (2021) noted the extension of the CCR model to handle panel data, which considerably enhanced its versatility and usability in empirical studies. The model has shown remarkable flexibility and adaptability to address contemporary econometric challenges. However, Miladinov (2021) indicated a critical concern regarding the CCR model: its high sensitivity to nuisance parameters. Despite this concern, the CCR model remains an essential tool in the econometric toolkit due to its ability to provide consistent and efficient estimates in complex cointegrated relationships.

The CCR model continues to evolve, with ongoing research investigating its potential shortcomings and seeking extensions and modifications to further enhance its capability in empirical studies. The model's adaptability and capability to handle complex econometric issues make it a valuable tool in economic research.

3.15.1 Applications in Forestry and Agriculture

Due to its intrinsic capacity to solve complicated econometric difficulties, the Canonical Cointegrating Regression (CCR) model has recently attracted significant attention in the sectors of forestry and agricultural research. Khan et al. (2018) used the CCR model to analyze the long-term connection between agricultural production and factors including climate and fertilizer. The findings confirmed the value of the CCR model in the field of agricultural economics and offered strong empirical evidence for policymakers to take appropriate policies to increase agricultural output. Raihan et al., (2023a; 2023b) used the CCR model to investigate how deforestation affects local economies in the forestry sector. Their research showed that deforestation has a negative effect on local economies, which should encourage the implementation of conservation initiatives in forest-rich areas.

Similarly, Alhassan (2021) used the CCR model to explore the nexus between forest management and GDP expansion. The research showed a favorable link between the two, stressing the importance of sustainable forestry practices in driving economic growth. By exploring the long- and short-term link between agricultural loans and crop production, Chandio et al. (2020) provided additional validation of the CCR model's use in agriculture. The results of the research showed a statistically significant positive correlation, demonstrating the significance of providing sufficient finance for agricultural endeavors.

Raihan (2023c) and Raihan & Tuspekova (2022a) applied the CCR model to analyze the impact of climate change on agricultural yield and forest biomass, respectively. The findings suggested that climate change adversely impacts agricultural yield and forest biomass, providing vital empirical evidence for policymakers to implement suitable mitigation strategies. Overall, these studies provide critical insights into the applicability of the CCR model in agriculture and forestry research. The findings of these studies have significant implications for the implementation of sustainable forestry and agricultural practices, policy formulation, and addressing the challenges posed by climate change.

3.15.2 Strengths and Limitations

The Canonical Cointegrating Regression (CCR) model boasts numerous strengths when applied to forestry and agriculture, making it an attractive choice for researchers in these fields. However, like any analytical tool, it also has its limitations which need to be considered. One of the key strengths of the CCR model, as highlighted by Topcu (2021) and Sowah Jr & Kirikkaleli (2022), is its ability to deal with endogeneity problems, which is a common issue in econometric analysis. It addresses simultaneity bias, thereby improving the reliability of the findings. Furthermore, the CCR model does not necessitate the series to be stationary at the same order, a condition required in many other cointegration techniques.

The model is also acclaimed for its robustness in identifying long-term relationships between variables. Golkhandan & Mohammadian Mansoor (2020) underline its effectiveness in detecting cointegrating relationships among non-stationary time series data, making it particularly suitable for studies spanning over long periods. Kalaycı & Özden (2021) likewise echo this sentiment, stating the CCR's superiority in dealing with time series data.

However, despite these strengths, the CCR model has its limitations. Babarinde (2020) highlights that the CCR model may suffer from small sample bias, which could lead to inaccurate results if the dataset is not adequately large. The model's reliance on the assumption of cointegration is another potential pitfall, as pointed out by Topcu (2021). If the variables in question do not share a cointegrating relationship, the application of the CCR model may lead to spurious regression results.

3.16 Comparative Analysis

A comparative analysis of the ARDL, DOLS, and CCR models, especially in the context of forestry and agriculture, reveals a complex interplay of theoretical foundations, applications, and performances. On a theoretical level, all three models share a common goal of examining long-term relationships among variables. They each offer distinctive advantages for dealing with the peculiarities of time series data (Nwani et al., 2021). The ARDL model, however, shines in its capacity to handle a mix of stationary and non-stationary variables, a trait not shared by the other two models. On the other hand, both the DOLS and CCR models excel in their ability to address endogeneity issues, a capacity not as robust in the ARDL model (Elfaki et al., 2022).

In terms of application, all three models have seen widespread use in forestry and agriculture studies, with diverse and context-specific applications. The ARDL model, as showcased by Chandio et al. (2020a), has been particularly adept at examining the impacts of climate change on agricultural productivity. The DOLS model, on the other hand, has been instrumental in studies exploring the relationship between forestry exploitation and economic growth (Chandio et al., 2020b). The CCR model, meanwhile, has been effective in analyzing the cointegrating relationships among non-stationary time series data in forestry and agriculture studies (Nwani et al., 2021).

As for performance, it is somewhat subjective and dependent on the specific objectives and data constraints of the research. Chandio et al. (2020a) found the ARDL model to deliver superior results when dealing with shorter time series data, thanks to its flexibility with variable stationarity. On the contrary, in situations with large datasets, the DOLS and CCR models may offer more accurate results due to their robustness in addressing endogeneity and identifying long-term relationships among non-stationary variables (Elfaki et al., 2022).

It is necessary to describe the descriptive statistics for the variable that is used in the study before analyzing the results. The results of descriptive statistics is shown in Table 3.2. Rainfall anomaly has the highest standard deviation among all study variables. AL, FL, CO_2, and URB all have positive skewness, whereas RA and TA have negative skewness.

Statistics	AL	FL	₽CO2	RA	TA	URB
Mean	60.643	0.004	1.190	0.000	0.000	29.539
Median	60.583	0.004	1.033	-5.359	0.259	29.235
Maximum	61.074	0.006	1.922	157.841	0.859	34.472
Minimum	60.397	0.003	0.691	-216.659	-1.251	25.778
Std. Dev.	0.222	0.001	0.403	92.934	0.656	2.666
Skewness	0.465	0.423	0.548	-0.383	-0.692	0.294
Kurtosis	1.753	1.607	1.878	2.584	1.978	1.840
Observations	29	29	29	29	29	29

Table 3.2: Descriptive Statistics

Table 3.3 shows the results of unit root tests, namely ADF and PP. It is necessary to assess the order of integration among variables using the proper unit root test before predicting the elasticities. It will ensure the status of stationarity of variables, and none of the variables are integrated of order two to avoid spurious regression results. The ADF test results indicate that the rainfall anomaly (RA) is stationary at a level. While other variables are non-stationary, however, all variables become stationary at first difference. Hence, the ADF test confirms the common order of integration, i.e., I (1). However, we applied another test to check the stationarity of data, i.e., the Phillips-Perron (PP) test shows the same as per results of the ADF test.

Variables	ADF Test	P ' Test

	At level	At first difference	At level	At first difference
	Statistics	Statistics	Statistics	Statistics
FL	-1.399	-5.115***	-1.399	-5.114***
TA	-2.139	-3.786**	-2.899	-15.210***
RN	-4.772***	-8.877***	-4.775***	-9.469***
PCO2	-2.394	-10.782***	-1.287	-5.566***
AL	-2.433	-6.966***	-2.433	-8.358***
URB	-2.877	-3.436*	-2.190	-3.342*

Table 3.3: Unit root test results

Note. "*", "**", and "***" indicate the significance level at 10%, 5%, and 1%, respectively.

We determine the cointegration relationship among the variables after confirming the order of integration of the variables. For this, the ARDL Bounds test is used. The results of the Bounds test is presented in Table 3.4. The calculated Value of F statistics (3.407) is more significant than the tabulated upper bound value of F statistics (3.38) at a 5% significance level. Therefore, it implies that null of hypothesis of no cointegration among variables is rejected. Therefore, the ARDL Bounds test concludes that there is long-run relationship among the variables during the study period.

Test Statistic	Value	Signif.	I(0)	I(1)
F-statistic	3.407604**	10%	2.08	3
K	5	5%	2.39	3.38
		1%	3.06	4.15

Table 3.4: Bound test Results

Further, the study explores the long-run effects of climate change on forest coverage. Table 3.5 shows the ARDL model results. The coefficient of temperature anomaly is positive but insignificant at 1% significance level. It implies that temperature anomaly deteriorates the forest coverage in India.

Similarly, rainfall anomaly has a positive sign and is significant at 1% level of significance. Rainfall anomaly also leads to a decline in forest coverage in India. CO2 emissions also have a negative effect on forest coverage in India. An increase in CO2 emissions leads to a decline in forest coverage in India.

Variable	Coefficient	Std. Error	t-Statistic	Prob.
TA	0.000159	0.000414	0.384694	0.704700
RN	0.000004	0.000001	3.571368	0.002000
PCO2	0.013378	0.002189	6.110992	0.000000
AL	0.000642	0.001234	0.520444	0.608800
URB	-0.002185	0.000420	-5.208302	0.000100
C	0.013683	0.081035	0.168853	0.867700
ECM	-1.070947	0.191162	-5.602305	0.000000
R-squared	0.885665			
Adjusted R-squared	0.843542			
Durbin-Watson stat	2.128248			

Table 3.5: ARDL long run results

The DOLS and CCR are also used in this work to test the robustness of ARDL-based long-run outcomes. In Table 3.6, the DOLS findings demonstrated that CO_2 significantly degraded forest in India, but other variables did not significantly impact it.

Variable	Coefficient	Std. Error	t-Statistic	Prob.
TA	0.001024	0.000802	1.277199	0.257600
RN	0.000005	0.000003	1.788899	0.133700
PCO2	0.009199	0.002470	3.723974	0.013700
AL	0.001485	0.002539	0.584944	0.584000
URB	-0.000871	0.000582	-1.496512	0.194800

C	-0.063017	0.163552	-0.385301	0.715900
R-squared	0.982444			
Adjusted R-squared	0.91222			

Table 3.6: DOLS model results

While the results of the CCR Model in Table 3.7 depicted that RN, CO2 and URB had a significant impact on forest loss. Thus the results of the CCR model are corollary with ARDL-based long-run results. Thus, the findings are robust while estimating the model with various econometric tools.

Variable	Coefficient	Std. Error	t-Statistic	Prob.
TA	0.00002	0.00038	0.05953	0.95310
RN	0.00001	0.00000	4.51748	0.00020
PCO2	0.01306	0.00194	6.72519	0.00000
AL	0.00082	0.00124	0.66001	0.51610
URB	-0.00209	0.00038	-5.44353	0.00000
C	0.00045	0.08061	0.00559	0.99560
R-squared	0.850641			
Adjusted R-squared	0.816696			

Table 3.7: CCR model results

It is also evident that forest loss causes temperature increase leading to global warming and climate change. This is proved by applying Granger reverse causality. The following results substantiate the above statement.

Null Hypothesis	Observation	F static	Probability Value

FL does not Granger Cause TA	28	12.693	0.002

Table 3.8 Granger reverse causality for forest loss leading to global warming

The above results show that probability value is less than 5%, hence null hypothesis is rejected. Therefore, forest loss Granger cause temperature increase leading to global warming and climate change.

3.17 Conclusion

The impacts of climate change on forest ecosystems are significant. It affect everything, such as species distribution and forest structure. Increased frequency of forest disturbances, such as wildfires and pest outbreaks are also crucial concerns. Despite these challenges, forests display a degree of natural resilience, and human interventions have shown promise in enhancing this resilience. The coefficient of temperature anomaly is positive but insignificant at 1% significance level. It implies that temperature anomaly deteriorates the forest coverage in India. Similarly, rainfall anomaly has a positive sign and is significant at 1% level of significance. Rainfall anomaly also leads to a decline in forest coverage in India.

The complex interplay between CO2 emissions and forest ecosystems has revealed that elevated CO2 levels can have a broad spectrum of impacts on forests. From altering plant growth and productivity to influencing biodiversity and forest health, CO2 emissions are reshaping our forests in significant ways. These changes can, in turn, affect the role of forests as carbon sinks and regulators of atmospheric CO2, possibly creating feedback loops that could either amplify or mitigate climate change effects. DOLS findings demonstrated that CO_2 significantly degraded forest in India.

The impact of agricultural practices on forest ecosystems is significant. This review has highlighted various direct and indirect effects, from deforestation and habitat fragmentation to soil degradation, water pollution, and altered hydrological cycles. It has also revealed that agricultural expansion often occurs at the expense of forest ecosystems, causing substantial loss of biodiversity. However, the adoption of sustainable practices and well-planned land-use strategies can mitigate these impacts.

The phenomenon of urbanization, while bringing numerous benefits such as economic growth and societal development, presents significant challenges to forest ecosystems. This chapter has underscored the numerous factors driving urbanization in India, including population growth, economic development, industrialization, and rural-to-urban migration, each of which has direct and indirect impacts on forests. The ecological impacts of urbanization on forest ecosystems are manifold. Urban expansion often results in habitat loss and fragmentation, causing profound changes in biodiversity and species composition.

This habitat destruction can lead to the disappearance of native species and the proliferation of invasive ones, thereby altering the structure and function of forest ecosystems. Furthermore, urbanization can bring about shifts in ecosystem functions and processes, and contribute to pollution and other environmental stressors, exacerbating the pressures on forest ecosystems. Simultaneously, urbanization can also have substantial social and economic repercussions. It can alter human-wildlife interactions, with potential for increased human-wildlife conflict. It can impact the cultural and recreational values of forests as natural spaces become increasingly urbanized. Moreover, it can affect forest-based livelihoods and economic benefits, as forests are depleted or their resources are overexploited. There is another point which is remarkable in this study though urbanization lead encroachment of forest land with increased human-wildlife conflict. The study points out that urbanization has negative effect on forest loss, this could be explained as the urbanization increases the percent of stakeholders directly dependent on forest ecosystems are reduced. This happens as more and more population from villages in the forest periphery migrate to cities or urban areas for better prospects. Therefore leading to less dependence on forests.

This study confirmed the long-run cointegration among forest loss and its determinant when forest loss is used as the dependent variable. The study concludes that all climatic variables stimulate forest loss in long run. The empirical findings of this study reveal that the ARDL model has passed all the diagnostic tests successfully.

In light of these challenges, there are several recommendations for future research and monitoring efforts. Firstly, research should focus on understanding impacts of climate change on forests in local levels. This research will require long-term monitoring and data collection. Secondly, socioeconomic research is needed to understand the barriers to implementing adaptation measures

(Tei & Sugimoto, 2018; Kaur, R., & Pandey, 2021; Kumar et al., 2020). Lastly, there is a need for interdisciplinary research that integrates environmental science with social sciences, economics, and policymaking. Policy interventions and incentives can play a pivotal role in promoting sustainable agriculture and forest conservation. Policies that incentivize sustainable practices, penalize environmentally harmful ones, and promote integration of agriculture and forestry can significantly influence farmers' choices and land-use patterns (Dai et al., 2017; Lazos-Chavero et al., 2016).

Additionally, recognizing and strengthening traditional and community-based natural resource management practices can also contribute to sustainable outcomes (Rao et al., 2019; Rey Benayas & Bullock, 2012). In India, several policy interventions have been implemented with varying degrees of success. For instance, Sahoo et al., (2019) discuss how the National Agroforestry Policy 2014 has fostered the integration of trees into farming systems across the country. Furthermore, Qureshi, Singh & Hasan, (2018) highlight the role of Panchayati Raj Institutions (local self-governments) in managing common forest resources in Himachal Pradesh, which has effectively controlled over-exploitation and supported sustainable forest use. Such examples suggest the importance of appropriate policy mechanisms in achieving a balance between agricultural productivity and forest conservation.

Summary of the chapter

The chapter is a theoretical and empirical review for impact of climatic and non-climatic factors on forest loss in India. Forest ecosystems are sensitive to the climate in several ways, displaying a range of responses to the changing climate conditions. It was argued by Condon & Maxwell (2020) that climate change alters species distributions in the forest ecosystems. In the same line of discussion, a range of authors (for example, Kumar, Singh & Kalra, 2018; Lele, Joshi & Agrawal, 2008; Das et al., 2013; Ravindranath et al., 2012) have found that changes in temperature and precipitation patterns can hugely affect the rate at which trees grow.

Impact of climate change on forest composition and structure can lead to change in species distribution and range shifts. It can lead to altered growth and mortality patterns of tress and effects forest structures and biodiversity. The chapter gives a detailed review of impact of climate change on forest processes like changes in water availability and hydrological cycles, implications on carbon storage and sequestration and influence on nutrient cycling and ecosystem functioning.

Impact of climate change on forest distribution leads to increased frequency and intensity of wildfires, expansion of pest and disease outbreaks and extreme weather events. Apart from this there are serious impacts of CO2 emissions on forest health and resilience. For instance, in the central highlands of India, which are adorned with lush moist deciduous forests, research studies (Rai et al., 2017) have indicated that elevated CO2 levels could potentially lead to an increase in biomass accumulation. This essentially means that the trees, under the influence of more CO2, may grow more energetically (Kiboi et al., 2018) and accumulate a higher amount of biomass (Fan et al., 2020).

The chapter also discusses impact of agriculture on forest ecosystems. Many studies (ArroyoRodríguez et al., 2020; Kotir, 2011; Reddy et al. 2016; Reddy, 2017) have found that agriculture is a leading cause of deforestation, as forest lands are converted into agricultural lands to meet the escalating food demands of the global population. Negi et al. (2019) found that extensive groundwater extraction for agriculture in semi-arid regions of Rajasthan has lowered water tables, affecting the health of adjacent forest ecosystems.

There are many important impact of urbanization on forest ecosystems. Like habitat loss and fragmentation, changes in biodiversity and species composition alterations in ecosystem functions and processes. There are social and economic consequences of urbanization on forest ecosystems. This chapter explore the impact of temperature, rainfall, per capita CO2 emission, agriculture and urbanization on forest loss in India using Auto-regressive Distribution Lag Model (ARDL).

This study confirmed the long-run cointegration among forest loss and its determinant when forest loss is used as the dependent variable. The study concludes that all climatic variables stimulate forest loss in long run. The empirical findings of this study reveal that the ARDL model has passed all the diagnostic tests successfully.

Chapter 4: Institutional analysis for sustainable forest management in India

4.1 Introduction of the institutional landscape and the complexities involved.

Forest management in India is a complex interplay of multiple institutional actors and policy mechanisms. The central body for forest management, the Ministry of Environment, Forest and Climate Change (MoEFCC), formulates policies and oversees their implementation at the state level (Dhanwantri et al., 2021). State Forest Departments manage the forests, guided by the Indian Forest Act of 1927 and the Forest Conservation Act of 1980 (Saxena et al., 2021). Meanwhile, the Forest Rights Act of 2006 has marked a significant shift, recognizing the rights and roles of indigenous communities in forest conservation (Blackie et al., 2014; Dhanwantri et al., 2021).

Forest management in India has undergone significant transformation over the centuries. Prior to colonial rule, forests were communally managed, and the local communities had a considerable say in their use and conservation (Gupta, 2014). This changed with the advent of British colonial rule in the 19th century. The British administration imposed strict state control over forests, primarily viewing them as revenue sources and for meeting Britain's timber demands (Jana, Lise, and Ahmed, 2014). This led to the disenfranchisement of local communities and deterioration of forest health due to overexploitation (Brandt et al., 2017). In the post-colonial era, the 1952 National Forest Policy continued the centralized control over forests while acknowledging the need to link forest policy with tribal welfare (Haq et al., 2022; Lutz et al., 2018). However, the focus on revenue generation and industrial demands persisted, leading to further forest degradation (Edmunds and Wollenberg, 2013). It wasn't until the late 1980s and early 1990s that a significant shift towards community participation and sustainable forest management started to appear (Maraseni et al., 2019).

The National Forest Policy of 1988 emphasized environmental stability and ecological balance, recognizing forests' pivotal role in supporting tribal and rural livelihoods (Panwar & Dhote, 2022). The pivotal Forest Rights Act (FRA) of 2006 further democratized forest management by recognizing the rights of forest-dwelling communities and their indispensable role in forest conservation (Pant & Pant, 2017). The shift towards community participation and sustainable forest management initiated by the 1988 National Forest Policy and solidified by the 2006 Forest Rights Act marked significant progress (Maraseni et al., 2019; Pant & Pant, 2017). These policies were crucial in acknowledging the role of forest-dwelling communities in conservation efforts and balancing economic and ecological concerns (Panwar & Dhote, 2022). However, these policy shifts have arguably not fully translated into practice.

This chapter is organized into distinct yet interconnected sections, first presents an overview of India's forests, discussing their history, current status, challenges, and significance to the nation's economy and ecology. The subsequent section delves into the roles of various institutions, including central and state governments and non-governmental institutes, involved in managing these forests. The chapter then addresses the roles these institutions play in sustainable forest management, focusing on policy, conservation, community engagement, and research. The legal framework and political impacts on forest management form another crucial segment of the chapter. Ten successful case studies from India are discussed to elaborate on different strategies (policies and institutional roles and coordination) for achieving sustainable forest management.

Theoretical framework for sustainable forest management in India: IAD Framework

The Institutional Analysis and Development Framework (IAD) investigates how people (actors) interact with Common Pool Resources (CPRs), which are rivalrous and non-excludable economic goods and resources (Ostrom et al., 1994). The institutional analysis for sustainable forest management in India is based on the IAD framework (Ostrom et al., 1994). The IAD framework offers a comprehensive tool for analyzing the multifaceted interactions between actors and Common Pool Resources (CPRs), such as forests. Forests in India are quintessential examples of CPRs, characterized by their rivalrous yet non-excludable nature (Dhanwantri et al., 2021). The IAD framework's ability to dissect and understand the complex institutional arrangements surrounding the management of such resources makes it an ideal candidate for this analysis.

The diagrammatic representation of the theoretical framework is given in Figure 4.1. The baseline condition has three parts: physical attributes, community attributes, and rules that already exist for the resource. In the case of this thesis, it is the forest resource. The physical attribute comprises variables like the rate of growth of respective forests, diversity of species present in the forest, climate and weather terrain, size of the resource, temporal and spatial variability, current condition, etc. The community attribute includes preferences, distribution of resources, level of common understanding about action situations, accepted norms of behavior etc. Rules include action required, action permitted, action prohibited, sanction etc. Based on the baseline condition of the respective forests, the action situation comes into play, where actors and situations interact in a pattern for a respective case. This interaction pattern leads to institutional mechanisms leading to outcomes. The outcomes have evaluative criteria which lead to policy reforms. The policy reforms then again influence the baseline conditions in different ways.

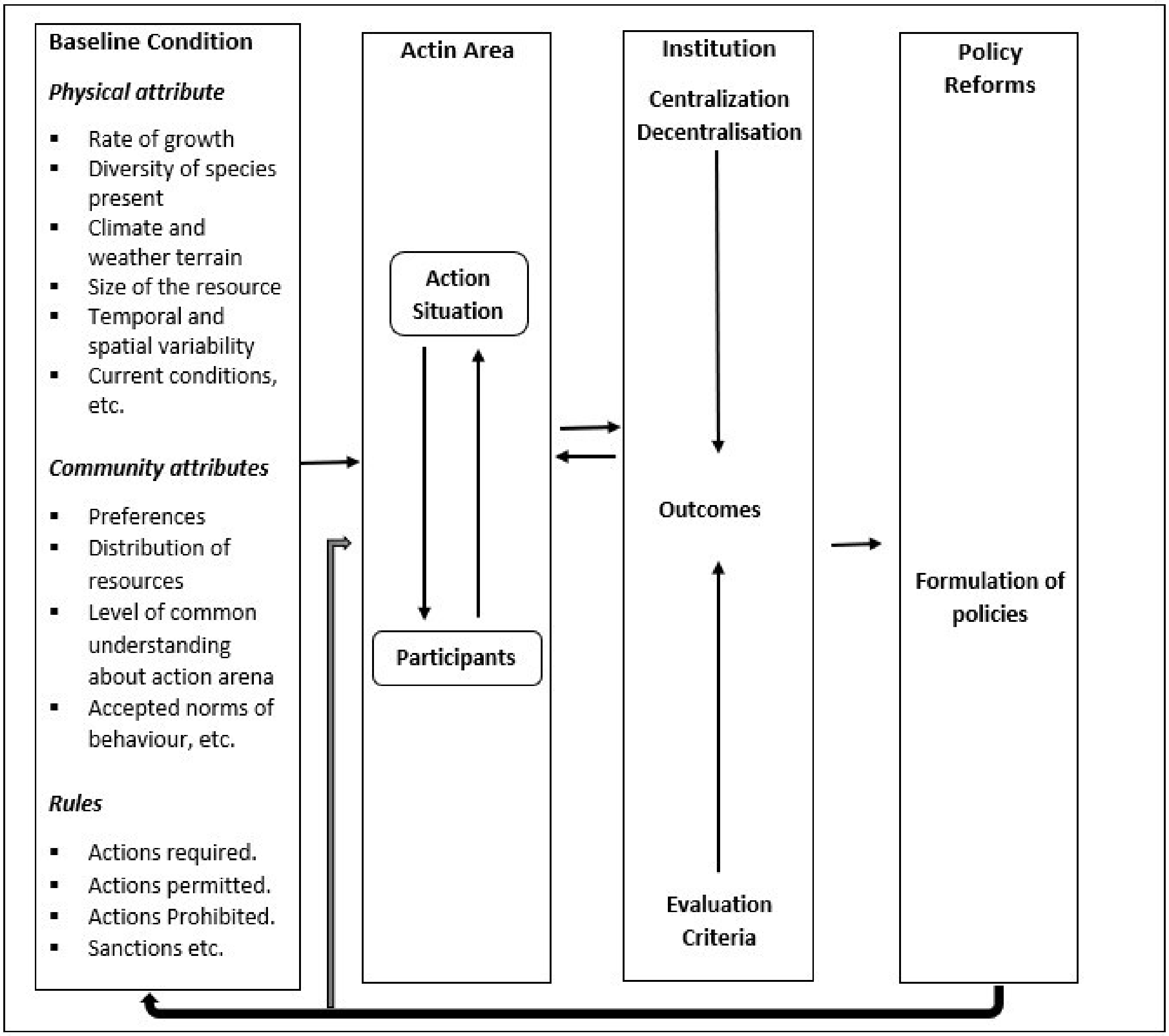

Figure 4.1: Theoretical framework

Source: Adapted from Ostrom et al. (1994)

At the heart of the IAD framework's applicability to forest management in India is its emphasis on the baseline conditions: physical attributes, community attributes, and pre-existing rules governing the resource (Ostrom et al., 1994). India's forests are diverse, both in terms of their ecological characteristics and the socio-economic context of the communities that interact with them. Critically, the IAD framework shines a light on the "action situation" – the core interactions between actors and the forest resource. This aspect is crucial in the Indian context, where a myriad of stakeholders, including local communities, governmental bodies, and non-governmental organizations, engage with forests in ways that are both cooperative and conflictual. The framework's focus on institutional mechanisms and outcomes offers valuable insights into how these interactions can lead to sustainable management practices or, conversely, to degradation and conflict.

4.2 Institutions for Forest Management

4.2.1 Central government institutions and their roles

Ministry of Environment, Forest and Climate Change (MoEFCC): The Ministry of Environment, Forest and Climate Change (MoEFCC), established in 1985, is the central institution responsible for formulating and overseeing the implementation of policies relating to environment, forests, and climate change (Aram and Arul, 2017). The main objective of MoEFCC is to conserve and preserve the country's ecological balance and natural heritage, which includes forests, rivers, lakes, biodiversity, and wildlife (Véron and Fehr, 2011). However, the effectiveness of MoEFCC policies and directives is contingent on the level of coordination and cooperation with state-level institutions and the implementation capacity at the local level (Ghosh et al., 2015).

A s the apex body, MoEFCC embodies the IAD framework's emphasis on setting and modifying rules in use, crucial for managing CPRs. However, the challenge lies in translating national policies into effective local actions, reflecting the IAD's focus on the need for congruence between institutional arrangements and local conditions.

Indian Council of Forestry Research and Education (ICFRE): The Indian Council of Forestry Research and Education (ICFRE), an autonomous organization under the MoEFCC, was established in 1986 (Arul Aram and Arul, 2018; Aram and Arul, 2017). ICFRE's mission is to conduct forestry research, transfer technology, and provide forestry education to fulfil the country's current and future requirements (Aram and Arul, 2017). The council's research and education play a vital role in informing policy and practice in forestry management (Ghosh et al., 2015; Kulkarni, Shah, and Shankar, 2015). They help to bridge the gap between scientific knowledge and field level implementation.

ICFRE's role in research and education is pivotal for generating knowledge – a critical aspect of the IAD framework. This knowledge informs policy and practice, emphasizing the IAD's principle that understanding resource characteristics and technological opportunities is vital for sustainable management.

Forest Survey of India (FSI): Established in 1981, the Forest Survey of India (FSI) is an organization under the MoEFCC responsible for assessing the country's forest resources (Kulkarni, Shah, and Shankar, 2015). Its main aim is to conduct a survey and assessment of forest resources in the country (Persha and Andersson, 2014). FSI plays a significant role in sustainable forest management in India by providing necessary data and technical inputs. However, there have been critiques about the adequacy and accuracy of FSI's assessments, suggesting the need for constant methodological improvements and ground-trothing to validate the remote-sensed data (Krishnakumar and Roy, 2021).

FSI provides essential data for decision-making, aligning with the IAD framework's recognition of the importance of accurate information in managing CPRs. The accuracy and reliability of this information are crucial for effective policy formulation and implementation.

Indira Gandhi National Forest Academy (IGNFA): The Indira Gandhi National Forest Academy (IGNFA) was founded in 1987 to provide training to the Indian Forest Service (IFS) officers. IGNFA is located in Dehradun, Uttarakhand, and is a crucial institution for developing professional foresters for the country (Kulkarni, Shah, and Shankar, 2015). IGNFA's primary role is to educate and train IFS officers, who are responsible for managing the country's forest resources. Training and capacity building by IGNFA are crucial for enhancing the capabilities of actors, a key element in the IAD framework. The quality of training impacts the effectiveness of forest management, highlighting the IAD principle that the attributes of the community (actors) significantly influence outcomes.

Institutes	Key Roles	Contributions
Ministry of Environment, Forest and Climate Change (MoEFCC)	Formulating and overseeing the implementation of policies relating to environment, forests, and climate change. Making environmental legislation, managing the country's forest cover and wildlife. Overseeing environmental impact assessments, managing protected area networks.	Helps to conserve and preserve the country's ecological balance and natural heritage.
Indian Council of Forestry Research and Education (ICFRE)	Conducting forestry research, transfer technology, and provide forestry education. Developing strategies and techniques for sustainable forest management and biodiversity conservation.	Informs policy and practice in forestry management.
Forest Survey of India (FSI)	Assessing the country's forest resources. Conducting the National Forest Inventory (NFI). Using remote sensing technology to monitor changes in forest cover, land use patterns, and to identify deforestation hotspots.	Provides necessary data and technical inputs for sustainable forest management in India.
Indira Gandhi National Forest Academy (IGNFA)	Providing training to the Indian Forest Service (IFS) officers. Educating and training IFS officers in various aspects of forest management, environmental conservation, wildlife management, and other related subjects.	Develops professional foresters for the country.
National Afforestation and Eco-Development Board (NAEB)	Promoting afforestation, tree plantation, ecological restoration, and eco-development activities. Coordinating and monitoring action plans for afforestation and eco-development.	Instrumental in implementing afforestation projects and promoting community participation
National Tiger Conservation Authority (NTCA)	Ensuring the conservation of tigers and their habitats in India. Overseeing and working with the state governments in managing the Project Tiger.	Vital in the resurgence of tiger populations in India.

Table 4.1: Summary findings of Central government institutions and their roles

National Afforestation and Eco-Development Board (NAEB): The National Afforestation and Eco-Development Board (NAEB) was set up in 1992 by the MoEFCC (Aram and Arul, 2017). Its primary objectives are to promote afforestation, tree plantation, ecological restoration, and ecodevelopment activities in the country (Persha and Andersson, 2014). NAEB has been instrumental in implementing afforestation projects and promoting community participation in forest management. However, the effectiveness of the afforestation programs has been mixed due to various challenges such as poor survival rates of planted trees and weak community participation (Pradesh, 2019).

NAEB's initiatives promote community involvement in forest management, resonating with the IAD framework's emphasis on the role of local communities in sustainable resource management. However, challenges in engagement and participation reflect the IAD's focus on the complexities of collective action.

National Tiger Conservation Authority (NTCA): The National Tiger Conservation Authority (NTCA) was established in 2005 following the amendment of the Wildlife (Protection) Act, 1972. Its mandate is to ensure the conservation of tigers and their habitats in India (Aram and Arul, 2017). NTCA oversees and works with the state governments in managing the Project Tiger, which aims to protect tigers in their natural habitats. It also provides information on tiger conservation and conducts tiger census across the country (Véron and Fehr, 2011).

NTCA's conservation efforts underscore the IAD's attention to the protection of biodiversity as part of sustainable CPR management. The balance between tiger conservation and community livelihoods reflects the IAD principle that managing CPRs involves negotiating complex tradeoffs.

4.2.2 Regional institutions and their responsibilities

The following section presents different state forest departments and their challenges and responsibilities.

North India

The Uttar Pradesh Forest Department is dedicated to the conservation, management, and enhancement of the state's extensive forest resources, aiming to maintain ecological balance while fostering sustainable development (Barbora, 2017). Its responsibilities include preserving biodiversity, expanding forest cover, and promoting community participation in forest management (Leisher et al., 2016). Despite its commitments, the department confronts challenges such as habitat degradation, human-wildlife conflicts, and the illegal exploitation of forest resources.

The Bihar Forest Department was founded with the objective of protecting, conserving, and managing the diverse forest resources in the state of Bihar (Chakrabarty, Pan, and Mandal, 2019; Smadja, 2018). The key goals of the department encompass not only the safeguarding of the state's rich biodiversity but also the establishment of an environment that supports sustainable livelihoods for local communities (Kashwan, 2016). However, Bihar has been struggling with deforestation, illegal logging, and forest encroachment, pointing to the need for the Department to bolster its enforcement measures and community outreach programs (Ghosh et al., 2015).

West India

Established to manage and conserve the rich forest resources in the state, the Maharashtra Forest Department's main objectives include forest conservation, wildlife protection, and forest resource development (Leisher et al., 2016). It also coordinates with local communities for forest conservation and livelihood improvement (Ghosh et al., 2015).

The Goa Forest Department was established to preserve, protect, and promote Goa's rich and diverse flora and fauna (Pradheeps, 2014; Anti-capitalist, 2022). The department's role includes maintaining existing forest cover, increasing green cover, preserving biodiversity, implementing soil conservation measures, and managing the wildlife in the state. It also aims to integrate local communities into conservation efforts (Leisher et al., 2016). However, critical reviews suggest that the department faces challenges such as land encroachments, mining activities, and issues of solid waste management affecting forest areas (Chakrabarty, Pan, and Mandal, 2019; Smadja, 2018).

South India

Kerala Forest Department is primary responsibilities encompass preservation and expansion of forest cover, protection of biodiversity, enforcement of forest laws, and promotion of research and training in forestry (Leisher et al., 2016). Yet, issues like deforestation, encroachments, poaching, and inadequate funds pose significant challenges. Critical evaluations recommend improved management through community-based forest management programs, stricter enforcement of forest laws, and enhanced infrastructure and funding (Persha and Andersson, 2014).

The Andhra Pradesh Forest Department, established under the mandate of conservation and enhancement of forest resources, primarily aims at balancing environmental stability with the sustainable development of the state (Barbora, 2017). However, the department has faced criticism for issues like illegal logging and mining, conflicts over forest land rights, and ineffective implementation of community-based forest management programs (Persha and Andersson, 2014).

Region	Key Roles	Contributions
North India (Bihar)	- Protecting, conserving, and managing diverse forest resources. - Supporting sustainable livelihoods for local communities	- Safeguarding biodiversity. - Struggling with deforestation and forest encroachment
North India (Uttar Pradesh)	- Conservation, management, and enhancement of the state's extensive forest resources - Preserving biodiversity, expanding forest cover	- Maintain ecological balance while fostering sustainable development
West India (Maharashtra)	- Forest conservation - Wildlife protection	- Conservation of rich forest resources. - Improvement of local livelihoods
West India (Goa)	- Preserving, protecting, and promoting flora and fauna	- Maintaining and increasing green cover.
South India (Kerala)	- Preservation and expansion of forest cover - Protection of biodiversity.	- Management improvement through community-based programs.
South India (Andhra Pradesh)	- Conservation and enhancement of forest resources - Balancing environmental stability with sustainable development	- Addressing illegal logging and mining - Implementing community-based forest management
East India (Odisha)	- Forest and wildlife conservation - Socio-economic development of forest dependent people	- Community forestry - Wildlife management
Central India (Madhya Pradesh)	- Forest protection and development - Wildlife conservation	- Conservation of vast forest resources
Central India (Chhattisgarh)	- Preserving abundant forest resources - Promoting sustainable use of forests for socio-economic development	- Addressing illegal mining and deforestation - Managing conflicts over forest rights
Northeast India (Assam)	- Sustainable use of forest resources - Protection of biodiversity	- Addressing deforestation and illegal wildlife trade
Northeast India (Arunachal Pradesh)	- Safeguarding and managing forest resources - Conservation of biodiversity community based management	- Addressing deforestation due to logging and shifting cultivation.

Northeast India (Meghalaya)	- Sustainable management and protection of forests. - Strengthening law enforcement.	- Conservation of diverse flora and fauna.

Table 4.2: Regional institutions and their responsibilities

East India

Odisha Forest Department was established with the aim of conserving the biodiversity of Odisha, the Odisha Forest Department is responsible for the management of forests, wildlife conservation, and the socio-economic development of people living in and around forests (Kulkarni, Shah, and Shankar, 2015). The department's work includes forest protection, reforestation, community forestry, and wildlife management. It also works on issues related to climate change and forests (Leisher et al., 2016).

Central India

The Madhya Pradesh Forest Department was established to conserve the state vast and diverse forest resources and enhance the livelihood of forest-dependent communities (Barbora, 2017; Hussain and Mahavidyalaya, 2021). The department is responsible for forest protection and development, wildlife conservation, and promoting participatory forest management (Chakrabarty, Pan, and Mandal, 2019; Smadja, 2018).

The Chhattisgarh Forest Department was established with the formation of the state in 2000 (Pradheeps, 2014; Anti-capitalist, 2022). Tasked with preserving the abundant forest resources of Chhattisgarh, the department aims to sustain the ecological balance while promoting the sustainable use of forest resources for socio-economic development (Pradheeps, 2014). Conversely, the department has faced significant challenges related to illegal mining, deforestation, and conflicts over forest rights, particularly with the indigenous tribal communities living in the forests (Anti-capitalist, 2022).

Northeast India

Established with the objective of preserving and expanding the state's forests, the Assam Forest Department seeks to foster the sustainable use of forest resources and protect the rich biodiversity of the state (Münster and Münster, 2012). The department faces significant hurdles, including rampant deforestation, illegal wildlife trade, and human-wildlife conflict. There's also criticism over the department's ineffective engagement with local communities, particularly tribal groups, in forest management (Nithya, 2014).

The Arunachal Pradesh Forest Department was created to safeguard and manage the state's vast forest resources, conserve its rich biodiversity, and ensure the welfare of communities dependent on these resources (Das and Hussain, 2016). The department's duties include enforcement of forest laws, promotion of afforestation, wildlife conservation, and driving community-based natural resource management initiatives (Leisher et al., 2016). Nonetheless, the department has been challenged by rampant deforestation due to logging, shifting cultivation, and infrastructural development (Banerjee, 2012).

The Meghalaya Forest Department was established to sustainably manage and protect the forest resources of Meghalaya, a state known for its diverse flora and fauna (Persha and Andersson, 2014). However, deforestation, illegal logging, and biodiversity loss are major concerns. The department needs to improve its forest management strategies, strengthen law enforcement, and increase local community participation in conservation efforts (Hazarika and Kalita, 2019).

4.2.3 Non-governmental institutions involved in forest management

Wildlife Trust of India (WTI): The Wildlife Trust of India (WTI) was founded in 1998 with the explicit objective to conserve India's natural heritage, focusing on the protection of wildlife and its habitats (Wright and Andersson, 2013). Through the years, it has worked towards this objective through initiatives that involve habitat preservation, mitigation of human-wildlife conflict, wildlife rehabilitation, and legal intervention (Persha and Andersson, 2014). The scale of deforestation, poaching, and human-wildlife conflict often exceeds the capacity of WTI to address effectively, pointing to the necessity for greater multi-institutional collaboration and support (Das and Hussain, 2016).

World Wildlife Fund - India (WWF-India): World Wildlife Fund - India, established in 1969, is part of the international WWF network, dedicated to delivering impactful conservation results on the ground (Abrams, 2019). Their work spans multiple areas, including the preservation of India's most iconic species, conservation of critical habitats, and climate change mitigation (Ghosh et al., 2015). WWF-India has significantly contributed to the sustainable management of forests through policy advocacy, research, field projects, and environmental education (Panwar and Chaudhry, 2019). Local communities often view these interventions as imposed and insensitive to their socioeconomic needs (Nithya, 2014).

Bombay Natural History Society (BNHS): The Bombay Natural History Society (BNHS), founded in 1883, is one of the oldest non-governmental organizations in India dedicated to nature conservation, biodiversity research, and promoting the cause of nature and wildlife (Savari, Eskandari Damaneh, and Eskandari Damaneh, 2020). The BNHS's objectives span from the conservation of nature to the study of various fauna and flora species, including their behavior, ecology, and distribution patterns. Yet, the organization has faced criticism for a perceived lack of engagement with the socio-economic realities of communities living in and around these forests (Das and Hussain, 2016).

Foundation for Ecological Security (FES): The Foundation for Ecological Security was established in 2001 with a focus on restoring degraded lands and water bodies, primarily focusing on communal lands in rural areas (Banerjee, 2012). FES has been instrumental in the sustainable management of forests, particularly in the areas of afforestation, water conservation, and promoting biodiversity. FES has received praise for its emphasis on community engagement, particularly in its role as a facilitator in ensuring local people are key stakeholders in conservation efforts (Ahmed et al., 2012).

Ashoka Trust for Research in Ecology and the Environment (ATREE): Established in 1996, ATREE's mission is to generate rigorous interdisciplinary knowledge for achieving environmental conservation and sustainable development (Münster and Münster, 2012). ATREE has made significant contributions to forest management, from conducting biodiversity research to influencing policy decisions at different levels. There is an ongoing need for increased collaboration and knowledge exchange between research institutions like ATREE and on-theground implementation bodies.

Nature Conservation Foundation (NCF): The Nature Conservation Foundation (NCF) is a nongovernmental wildlife conservation and research organization established in 1996 (Kulkarni, Shah, and Shankar, 2015). NCF's work aims to protect wildlife and habitats, resolve human-wildlife conflict, and promote environmentally sound development activities (Persha and Andersson, 2014). Their work has brought significant contributions to forest management, particularly their research on the human-wildlife conflict and its implications for conservation.

Despite their efforts, NCF faces challenges in translating their research into effective policy recommendations due to the often complex nature of environmental governance in India (Ghosh et al., 2015).

4.3 Coordination between Institutions

4.3.1 Formal mechanisms for coordination between different institutions

The diagram presents a structured model illustrating the formal mechanisms that underpin sustainable forest management in India. It delineates the foundational policies, namely the National Forest Policy (NFP) and the National Wildlife Action Plan (NWAP), which set the overarching goals for conservation. These policies guide and inform the actions of state-level institutions through State Forest Departments Coordination Meetings (SFDCMs), ensuring coherence and alignment with national objectives. At the grassroots level, Joint Forest Management Committees (JFMCs) facilitate community participation and local knowledge integration into forest management practices. This model emphasizes the interconnectedness of policy, administrative coordination, and community engagement in achieving sustainability in forest management.

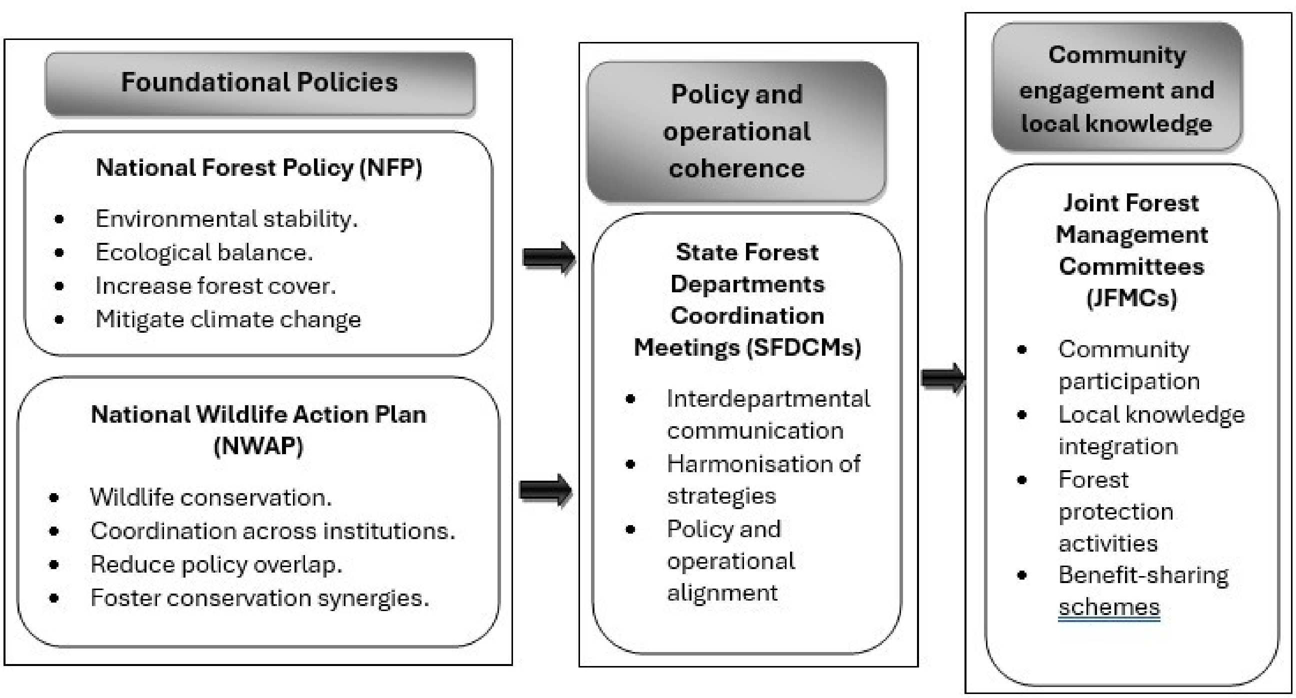

Figure 4.2 Formal mechanisms for coordination between different institutions

Foundational Policies: The National Forest Policy (NFP) and the National Wildlife Action Plan (NWAP) serve as the cornerstone of India's forest and wildlife conservation efforts. Both policies, overseen by the Ministry of Environment, Forest and Climate Change (MoEFCC), set out the overarching goals for preserving environmental stability, ecological balance, and India's rich biodiversity (Barnes and van Laerhoven, 2015; Caballero, 2015; Newton et al., 2015). The NFP focuses on increasing forest cover and mitigating climate change impacts, while the NWAP concentrates on safeguarding wildlife heritage through coordinated efforts across various institutions. However, the implementation of these policies often faces challenges due to discrepancies between objectives and practice, stemming from inadequate institutional capacity and resource limitations at the state level (Persha and Andersson, 2014; Chakrabarty, Pan, and Mandal, 2019).

Policy and Operational Coherence: State Forest Department Coordination Meetings (SFDCMs) are crucial for ensuring that the execution of strategies at the district level aligns with state and national forest policies. These meetings foster interdepartmental communication, exchange of experiences, and strategy harmonization across different administrative levels (Hazarika and Kalita, 2019; Barbora, 2017). SFDCMs aim to address key forestry management issues, review policy implementations, and tackle emerging challenges, contributing significantly to the coherent management of India's forests. Despite their potential, the effectiveness of SFDCMs can be hindered by factors such as communication quality, institutional capacity, and community engagement levels. Improvements in transparency, feedback mechanisms, and the systematic incorporation of scientific knowledge could enhance the outcomes of these meetings (Samal, Mili, and Dollo, 2019; Pradesh, 2019).

Community Engagement and Local Knowledge: Joint Forest Management Committees (JFMCs) embody the participatory approach to forest management, recognizing the importance of community involvement and local knowledge. By facilitating collaboration between State Forest Departments, local communities, and Village Forest Committees (VFCs), JFMCs play a key role in forest protection activities, benefit-sharing schemes, and decision-making processes (Persha and Andersson, 2014; Leisher et al., 2016; Kulkarni, Shah, and Shankar, 2015). While JFMCs represent a step forward towards decentralized forest management, their effectiveness is often debated due to challenges related to decision-making equity, participant quality, and local capacity building. Addressing these issues to ensure equitable participation and benefit-sharing is crucial for leveraging the full potential of JFMCs in sustainable forest management (Véron and Fehr, 2011; Edmunds and Wollenberg, 2013).

4.3.2 Informal links to other organisations

Informal links between various organizations related to forests in India often enhance the overall effectiveness and efficiency of forest management (Wright and Andersson, 2013).

Research collaborations between academic institutions and government forest departments are pivotal to driving the science-policy interface in forest management (Nithya, 2014; Münster and Münster, 2012). Such partnerships often result in the production of cutting-edge research that can shape policy development, inform management strategies, and contribute to monitoring and evaluation activities (Barnes and van Laerhoven, 2015). However, the integration of research findings into policy and practice is a complex process and may be hindered by institutional barriers, communication gaps, and the lack of capacity within forest departments to utilize scientific knowledge (David and Eva, 2013).

Partnerships between NGOs and government agencies play a significant role in implementing conservation projects and conducting awareness campaigns (Das and Hussain, 2016; Kashwan, 2016). They help in mobilizing resources, promoting community participation, and reaching out to wider audiences (Leisher et al., 2016). However, the success of these partnerships largely depends on mutual trust, shared objectives, and equitable power dynamics (Newton et al., 2015).

Networks of forest officials, researchers, and conservationists sharing knowledge and best practices through conferences, workshops, and online forums enhance the professional development of individuals involved and foster the dissemination of innovative practices (Samal, Mili, and Dollo, 2019; Pradesh, 2019). Nonetheless, the reach and effectiveness of such networks may be constrained by language barriers, access to technology, and the need for active facilitation and engagement (Caballero, 2015).

Collaboration between local communities, NGOs, and government agencies in community-based forest management initiatives can foster local stewardship of forest resources, improve forest health, and enhance livelihood outcomes (Ghosh et al., 2015). Yet, the success of these initiatives relies on addressing issues of power imbalances, ensuring local capacity and rights recognition, and creating supportive policy environments (Edmunds and Wollenberg, 2013).

4.4 Case studies of successful inter-institutional coordination

Case 1: Joint Forest Management (JFM) in West Bengal: Joint Forest Management (JFM) has been an innovative institutional mechanism fostering collaboration between the Forest Department and local communities. The implementation of JFM in Arabari Forest in West Bengal presents a successful example of inter-institutional coordination (Gupta, 2013). Here, the Forest Department and local villagers jointly agreed upon the protection and management of the forest, with benefits shared between them (Ghosh et al., 2015). This initiative led to increased forest cover, enhanced livelihood opportunities, and improved community participation in forest management (Bhojvaid et al., 2016). However, the long-term success of JFM initiatives depends on addressing challenges related to equitable benefit-sharing, local capacity-building, and the recognition of community rights over forest resources (Rai et al., 2012).

In West Bengal, the Joint Forest Management (JFM) initiative serves as a prime example of successful inter-institutional coordination, aligning closely with the IAD framework's principles. The collaboration between the Forest Department and local communities, as seen in the Arabari Forest, underscores the significance of shared decision-making and benefit-sharing in managing forest resources. This case exemplifies the IAD's focus on creating institutional arrangements that enable collective action by integrating local knowledge and preferences into forest management, leading to improved forest cover and community livelihoods. Challenges such as equitable benefit sharing and local capacity-building remain essential considerations for the sustainability of such initiatives.

Case 2: The Corbett Tiger Reserve: The Corbett Tiger Reserve in Uttarakhand represents a successful example of coordination between the National Tiger Conservation Authority, the State Forest Department, and local communities (Amarnath, Babar, and Murthy, 2017). This partnership resulted in the enhanced protection of the tiger habitat, increased tiger population, and improved socio-economic conditions of local communities through eco-tourism (Saxena et al., 2021). However, potential issues such as human-wildlife conflict and the displacement of local communities due to reserve establishment need to be addressed through balanced policies that consider both conservation and human rights (Dhanwantri et al., 2021).

The coordination efforts in the Corbett Tiger Reserve illustrate the IAD framework's emphasis on multi-level governance and the role of policy in shaping action situations. The partnership among the National Tiger Conservation Authority, the State Forest Department, and local communities facilitated the protection of tiger habitats and fostered socio-economic benefits through ecotourism. This case highlights the importance of balancing conservation objectives with community rights and livelihoods, a critical aspect of the IAD framework that ensures the sustainability of conservation efforts.

Case 3: The Forest Rights Act (FRA) Implementation in Odisha: The implementation of the Forest Rights Act (FRA) in Odisha illustrates effective coordination between State Government institutions and local communities (Islam and Bhuiyan, 2018). The recognition of community forest rights under FRA resulted in enhanced forest conservation and improved livelihoods as communities had legal access and management rights over forest resources (Mollick et al., 2022). Despite its success, challenges like bureaucratic hurdles, lack of awareness, and the slow pace of rights recognition need attention to fully realize FRA's potential (Mahmood et al., 2021).

The implementation of the Forest Rights Act (FRA) in Odisha showcases effective interinstitutional coordination by granting communities legal access and management rights over forest resources. This aligns with the IAD framework's recognition of the need for legal and institutional frameworks that empower local communities and facilitate their participation in resource management. However, addressing bureaucratic challenges and increasing awareness are vital for harnessing the full potential of community-led forest conservation efforts.

Case 4: The Van Panchayat System in Uttarakhand: The Van Panchayat system in Uttarakhand, wherein village communities manage their adjacent forests, is a classic case of successful inter-institutional coordination (Badola et al., 2017). The local communities, facilitated by the State Forest Department, were able to ensure sustainable forest use, preserving the forest ecosystem while catering to their livelihood needs (Samom, 2020). However, issues like inequitable resource distribution, external pressures, and lack of technical support present challenges to this community-based forest management system (Thongam and Meitei, 2021).

The Van Panchayat system in Uttarakhand represents a successful model of community-based forest management, resonating with the IAD framework's emphasis on local governance and community engagement in sustainable resource use. This case illustrates how decentralized governance structures can enhance forest conservation while supporting local livelihoods.

However, addressing challenges such as inequitable resource distribution and external pressures is crucial for the resilience and effectiveness of these community-managed forests.

Case 5: Private-Public Partnerships for Afforestation: Public-private partnerships, like the one between ITC Limited and the Madhya Pradesh Forest Department for afforestation, showcase how the private sector can contribute to sustainable forest management (Rawat and Adhikari, 2015). The partnership led to significant afforestation efforts, the creation of jobs, and the sequestration of carbon (Puyravaud and Davidar, 2013). However, such collaborations need clear objectives and strong monitoring mechanisms to ensure environmental integrity and social fairness (Rawat and Adhikari, 2015).

Public-private partnerships for afforestation, like the collaboration between ITC Limited and the Madhya Pradesh Forest Department, demonstrate the potential of engaging the private sector in sustainable forest management. This case aligns with the IAD framework's perspective on the role of diverse actors in resource management and the importance of clear objectives and robust monitoring mechanisms. Such collaborations can contribute significantly to afforestation efforts, job creation, and carbon sequestration, provided they maintain environmental integrity and social fairness.

4.5 Role of Institutions in Sustainable Forest Management

The role of institutions in Sustainable Forest Management (SFM) is multifaceted and complex, with responsibilities ranging from policy formulation and implementation to driving forest conservation and preservation initiatives (Maginnis and Sayer, 2013).

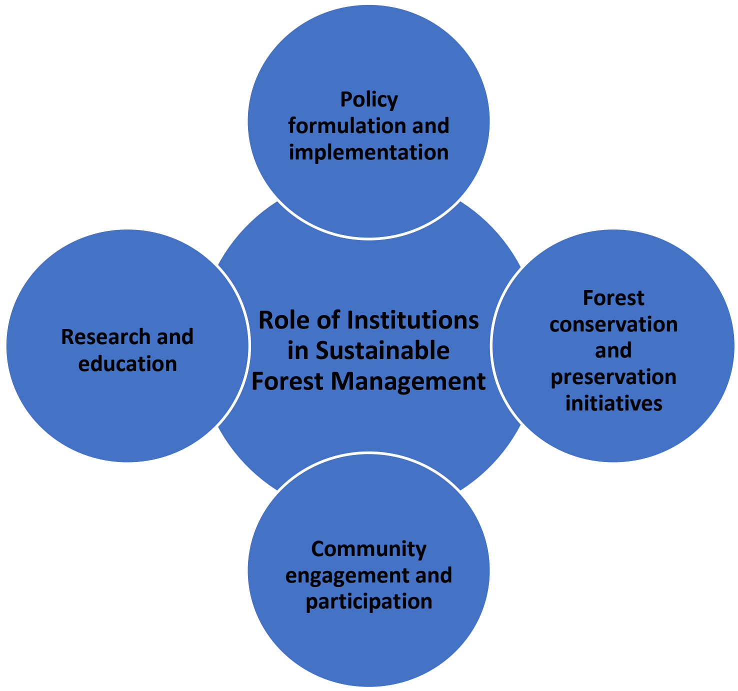

Figure 4.3: Role of Institutions in Sustainable Forest Management

Source: Maginnis and Sayer, 2013

Policy formulation and implementation: Institutions play a key role in the formulation of policies that guide sustainable forest management (Jhariya, Banerjee and Yadav, 2019). These policies set the regulations, standards, and best practices for forest management, intending to balance the need for forest products, biodiversity conservation, and the well-being of communities relying on forest resources (Sheppard et al., 2020).

Forest conservation and preservation initiatives: Institutions are also at the forefront of initiatives aimed at conserving and preserving forests. These initiatives often involve measures to safeguard forest biodiversity, protect endangered species, and restore degraded forest lands (Coleman and Mwangi, 2013' Fagan et al., 2020). A prime example is the Bihar Forest Department's efforts towards implementing afforestation programs and managing the state's wildlife sanctuaries (Ghosh et al., 2015). Several case studies highlight successful models of institutional roles in SFM. In the state of Chhattisgarh, for example, the Forest Department has effectively combined forest conservation with socio-economic development by promoting sustainable use of forest resources and implementing community-based forest management programs (Romañach et al., 2018).

Community engagement and participation: Community engagement and participation are fundamental to the role of institutions in Sustainable Forest Management (SFM) (Ojha et al., 2016; Singh, 2013). Given that many forest-dependent communities rely heavily on forest resources for their livelihoods, integrating their knowledge and values into SFM policies is crucial for the long-term sustainability of these ecosystems (Dyer et al., 2014; Reed et al., 2018). In India, numerous examples exist of institutions facilitating such engagement.

Research and education: Institutions also play a pivotal role in fostering research and education related to SFM. This responsibility includes generating and disseminating knowledge about forest ecosystems, their management, and their conservation, which is critical for policy formulation and implementation, as well as for enhancing public awareness about the importance of SFM (Sheppard et al., 2020; SA and Rica, 2016). In India, research institutions such as the Forest Research Institute (FRI) and various agricultural universities conduct extensive research on various aspects of forestry and SFM (Islam, Rahman, Fujiwara, and Sato, 2013; Newton, Miller, Byenkya, and Agrawal, 2016).

4.6 Political and Legal Considerations in Forest Management in India

Legislation governing forest management in India: India has a broad legislative framework governing forest management, key among which is the Indian Forest Act of 1927 and the Forest (Conservation) Act of 1980. The former provides the basis for forest governance and regulation, while the latter primarily addresses deforestation and forest conversion for non-forest uses (Dash and Behera, 2015; Gupta, 2014). A significant step was the introduction of the Forest Rights Act (FRA) in 2006, which acknowledges and grants legal recognition to the rights of forest-dwelling communities (Divan and Rosencranz, 2022; Springate-Baginski and Blaikie, 2013).

Impact of political decision-making on forest management in India: Political decisions have a profound impact on forest management in India. In recent decades, there has been a trend towards decentralisation and the devolution of forest management responsibilities to local communities (Edmunds and Wollenberg, 2013; Cronkleton, Pulhin, and Saigal, 2012). This shift has been driven by the recognition of the potential benefits of involving communities in forest management, including improved conservation outcomes and enhanced livelihood opportunities (Leisher et al., 2016; Puettmann et al., 2015).

The role of the judiciary in forest management in India: The judiciary has played a significant role in forest management in India, often acting as a bulwark against environmentally damaging activities and upholding the rights of forest-dependent communities (Ashutosh and Roy, 2021). Landmark judgements, such as the Godavarman case, have expanded the scope of forest conservation and reasserted the role of the judiciary in protecting the environment (DasGupta and Shaw, 2013). However, the judiciary's role is not without controversy. Critics argue that judicial interventions can sometimes undermine the rights of local communities and compromise the principles of democratic decision-making (Mogoi et al., 2012).

4.7 Contributions from Different Levels of Government in Forest Management

The model (Figure 4.3) of contributions from different levels of government in forest management in India presents a layered and collaborative approach towards achieving sustainable forest management, as elucidated through various policies, programs, and their impacts across national, state, and local governance levels, alongside the essential role of institution and stakeholder participation.

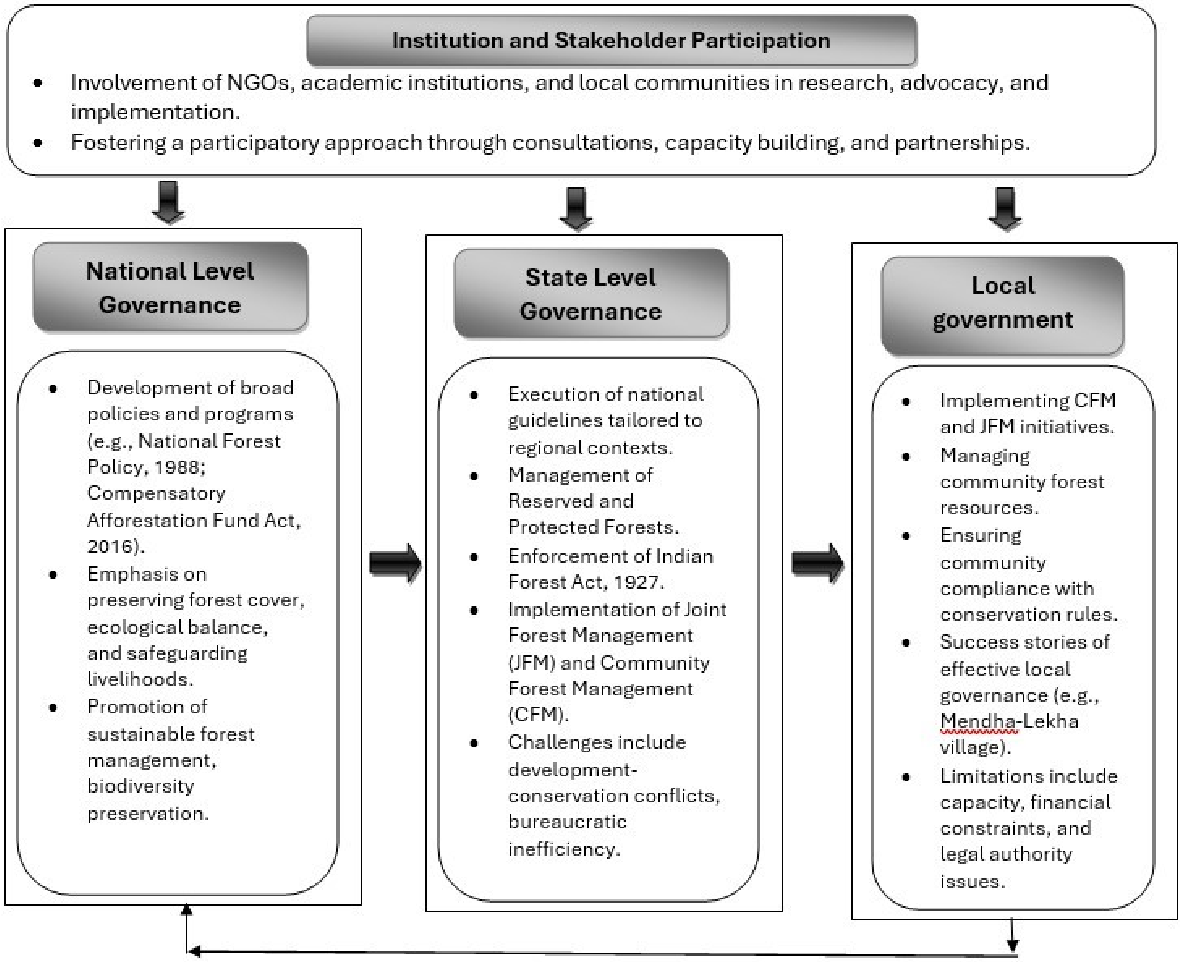

Figure 4.4: Contributions from Different Levels of Government in Forest Management

At the national level, the Government of India, particularly through the Ministry of Environment, Forest, and Climate Change, shapes the foundational policies and programs such as the National Forest Policy, 1988 (NFP, 1988), and the Compensatory Afforestation Fund Act, 2016. These initiatives underscore the importance of preserving forest cover, promoting ecological balance, and ensuring the livelihood of forest-dependent communities (Gupta, 2014; Dash and Behera, 2015). Their implementation is aimed at fostering sustainable forest management, which has contributed to the preservation and expansion of forest cover, increased carbon sequestration, and enhanced protection of community rights (Edmunds and Wollenberg, 2013).

The state level governance takes the mantle of executing these broad national guidelines, customizing them to fit regional specificities. State governments manage Reserved and Protected

Forests and enforce forestry laws, grappling with challenges like bureaucratic inefficiency and conflicting development-conservation interests (Springate-Baginski and Blaikie, 2013; DasGupta and Shaw, 2013; Nagendra and Ostrom, 2012).

Local governance layers, particularly Panchayati Raj Institutions and local forest committees, implement community-based forest management initiatives, facing challenges such as limited capacity and financial constraints (Ashutosh and Roy, 2021; Cheng et al., 2019; Mogoi et al., 2012). Successful examples, like Mendha-Lekha village, demonstrate the potential of effective local governance in forest conservation.

Institution and stakeholder participation cuts across all levels, with NGOs, academic institutions, and communities playing critical roles in research, advocacy, and implementing conservation strategies. This participatory approach is vital for the inclusiveness and effectiveness of forest management (Puettmann et al., 2015; Newton, Miller, Byenkya, and Agrawal, 2016).

4.8 Decentralization of forest management in India

Decentralization in forest management involves transferring authority and responsibility for decision-making, planning, and management from central government institutions to subnational governments, local communities, or private enterprises (Colfer and Capistrano, 2012; Capistrano and Colfer, 2012). The pros of decentralization are substantial. Firstly, it promotes greater participation and inclusion of local communities, improving equity in forest resource management (Lund, Rutt, and Ribot, 2018; Samii et al., 2014). Secondly, it empowers local governments, allowing for more effective local-level decision making that reflects local conditions, values, and priorities (Gupta, 2014). Thirdly, it can lead to improved forest conservation outcomes, as locally devised strategies often align with traditional knowledge systems and sustainable use of resources (Pacheco, 2012).

Capacity building for decentralized forest management: Capacity building for decentralized forest management involves equipping local actors with the necessary skills, knowledge, and resources for effective management (Leisher et al., 2016). This can involve training on sustainable forest management practices, facilitation of knowledge exchanges between communities, provision of technical support, and the strengthening of institutional capacity at the local level (Newton, Miller, Byenkya, and Agrawal, 2016). One of the key elements of capacity building is developing local institutions' ability to participate effectively in forest management, including enhancing their negotiation and decision-making skills, technical expertise, and administrative capacity (Singh, 2013). This should be complemented by efforts to enhance the economic capacity of local communities, such as through promoting sustainable forest-based livelihoods and facilitating access to markets (Dyer et al., 2014).

Institutional evolution post decentralization: Decentralization has significant implications for the evolution of institutions involved in forest management. The shift in decision-making authority requires the restructuring of existing institutions and the emergence of new ones, which can lead to changes in power relations and governance practices (Ojha et al., 2016). For instance, decentralization often results in greater involvement of local-level institutions such as Panchayati Raj Institutions (PRIs) and community forest committees in India, shifting power dynamics away from centralized forest departments (Coleman and Mwangi, 2013). This can lead to a greater sense of ownership and empowerment among local actors, fostering local innovation and problem solving (Wright and Andersson, 2013).

4.9 Understanding Indian Forest Institutional Mechanisms and Strategies

The following section discusses ten case studies that broadly discuss the strategies followed by respective forest departments (institutions) for mitigating or adapting to the challenges they face through institutional coordination and policies.

Indian case study 1: Vindhyan Tropical Forests in Madhya Pradesh – Joint Forest Management (JFM) with local communities.

Location of the Forest: The Vindhyan Tropical Forests are situated in the central Indian state of Madhya Pradesh, encompassing the Vindhya mountain range (Gupta, 2013). A number of endemic species may be found in this biologically important and varied location, which is also vital to the survival of nearby populations. The forest is characterized by its rich biodiversity, including numerous endemic flora and fauna, as well as unique geological features (Bhojvaid et al., 2016).

Importance of the Forests: These forests are immensely important for both ecological and socioeconomic reasons. Ecologically, they support a diverse range of wildlife, some of which are endangered or threatened, and contribute to maintaining overall ecosystem health (Amarnath, Babar & Murthy, 2017).

Concerns Related to the Forests: Deforestation and forest degradation brought on by human activities like logging, agriculture, and mining have been the main causes of worry for the Vindhyan Tropical Forests, which have resulted in habitat loss and fragmentation (Gupta, 2013).

Strategies: To address these concerns, various strategies of sustainable forest management were implemented, including the Joint Forest Management (JFM) approach. This entailed working together with local people and the forest service to manage and protect forests sustainably (Rai et al., 2012).

Outcomes and Successes: The implementation of these strategies has led to several positive outcomes, such as increased forest cover, improved biodiversity, and enhanced livelihood opportunities for local communities (Krishnakumar & Yadav, 2019).

Indian case study 2: Aravalli Biodiversity Park in Delhi – Rehabilitation of degraded mining area, community involvement.

Location of the Forest: The historic Aravalli mountain range is partially covered by the Aravalli Biodiversity Park, which is situated near Delhi, the capital of India (Panwar & Dhote, 2022).

Characteristics of the Forest: The park is exceptional for having a wide variety of plants and animals, including numerous endangered and indigenous species (Pant & Pant, 2017). Additionally, it harbors various ecosystems, such as grasslands, wetlands, and forests, contributing to its ecological value and making it an important refuge for wildlife in an urban setting (Saxena et al., 2021).

Importance of the forest: The Aravalli Biodiversity Park holds significant importance for various reasons. In terms of ecology, it offers vital ecosystem services including carbon sequestration, air and water purification, and the provision of habitat for a variety of species (Dhanwantri et al., 2021). Furthermore, it serves as a crucial green corridor connecting fragmented habitats, thus promoting biodiversity conservation in the region (Singh, Venkatramanan & Deshmukh, 2022).

Concerns: The primary concern for the Aravalli Biodiversity Park was the extensive degradation caused by mining activities, which led to habitat loss, soil erosion, and depletion of water resources (Panwar & Dhote, 2022). Moreover, rapid urbanization and infrastructure development in the surrounding areas posed threats to the remaining natural habitats, further exacerbating the ecological imbalance (Dhanwantri et al., 2021).

Strategies: To address these concerns, several sustainable forest management strategies were employed, including the rehabilitation of the degraded mining area through afforestation and reforestation efforts (Pant & Pant, 2017). Additionally, community involvement was actively encouraged, engaging local residents, schools, and non-governmental organizations in planting native species, maintaining the park, and participating in environmental education programs (Saxena et al., 2021).

Outcomes and Successes: By putting these tactics into practice, the Aravalli Biodiversity Park has successfully been restored, with higher forest cover, better biodiversity, and improved ecosystem services (Dhanwantri et al., 2021). Moreover, the park has become a valuable green space for local communities, fostering environmental awareness and appreciation for nature among its visitors (Saxena et al., 2021).

Indian case study 3: Sundarbans Mangrove Forest in West Bengal – Tiger conservation, mangrove protection.

Location of the forest: In the Ganges, Brahmaputra, and Meghna river deltas, India and Bangladesh are home to the Sundarbans Mangrove Forest, a UNESCO World Heritage site (Ghosh et al., 2015). This case study largely focuses on the Sundarbans in West Bengal, which are part of India (Islam & Bhuiyan, 2018).

Characteristics of the forest: The Sundarbans, the world's biggest continuous mangrove forest, is distinguished by a system of tidal canals, mudflats, and tiny islands (Mollick et al., 2022). The forest's unique salinity-adapted mangroves host a diverse range of wildlife, including the endangered Bengal Tiger. The region experiences tidal flux and is highly influenced by monsoons (Ghosh et al., 2015).

Importance of the forest: The Sundarbans are crucial for the environment. Important ecological services they offer include storm protection, carbon sequestration, water filtration, and fisheries production (Islam & Bhuiyan, 2018). The forest is a biodiversity hotspot, particularly significant for its tiger conservation efforts. It's also socially and economically vital for communities living in and around the forest, supporting livelihoods through fishing, honey collection, and wood gathering.

Concerns: Major concerns for the Sundarbans include deforestation, poaching, pollution, and climate change impacts. Deforestation driven by illegal logging and increased demand for fuelwood and forest products threatens the forest's health (Islam & Bhuiyan, 2018). Poaching poses a significant threat to wildlife, particularly the Bengal Tiger. Pollution from upstream industries and agricultural runoff deteriorates water quality (Chandra & Mukhopadhyay, 2022).

Strategies: To address these concerns, various strategies have been applied. Tiger conservation efforts have intensified, with anti-poaching measures and monitoring programs. Mangrove reforestation initiatives and strict regulation of forest product extraction combat deforestation (Mollick et al., 2022; Islam, 2016).

Outcome and success: The strategies resulted in notable successes, including reduced rates of deforestation and poaching and improved tiger populations. Community engagement strategies fostered a sense of ownership and understanding among locals, improving sustainable practices (Chandra & Mukhopadhyay, 2022).

Indian case study 4: Keibul Lamjao National Park in Manipur – Floating biomass conservation, ecotourism.

Location and overview of the forest: The Keibul Lamjao National Park, perched in Manipur, India, is an extraordinary ecological marvel nestled on the southeastern shores of Loktak Lake (Badola et al., 2017). Renowned as the world's only 'floating' national park, it is a unique biodiversity hotspot, thereby attracting global attention (Leisangthem et al., 2012).

Forest Characteristics: The park's primary feature is the unique "phumdi" biomass, a floating ensemble of vegetation, soil, and organic matter in decomposition stages (Leisangthem et al., 2012). It shelters several endemic species, most notably the endangered Manipur Eld's deer, affirming its crucial role in sustaining biodiversity (Thongam & Meitei, 2021).

Importance of the forests: The Keibul Lamjao National Park's role in environmental conservation is multifold. The floating "phumdi" biomass serves as a significant carbon sink, absorbing carbon dioxide and contributing to global climate regulation efforts (Samom, 2020). Simultaneously, the park's diverse flora and fauna serve as a genetic reservoir, thereby bolstering biodiversity (Badola et al., 2017).

Concerns: Despite its ecological significance, the park faces the threat of "phumdi" degradation due to human activities, including indiscriminate fishing practices and exploitation of biomass resources (Thongam & Meitei, 2021). Increasing pollution levels, primarily resulting from urban runoff, have exacerbated the degradation process, leading to habitat loss and a decline in biodiversity (Okuno et al., 2017).

Strategies: The park's management has deployed several strategies to curb degradation. Measures have included restricting harmful fishing practices, implementing solid waste management programs, and promoting sustainable ecotourism to reduce human impacts (Samom, 2020; Rawat & Adhikari, 2015).

Outcomes and Success: These strategies have helped stabilize the "phumdi" biomass, thereby protecting the habitat of the Manipur Eld's deer and other species. Increased visitor awareness and local community involvement have fostered a conservation culture, strengthening the sustainable management of this unique forest ecosystem (Okuno et al., 2017).

Indian case study 5: Nilgiri Biosphere Reserve in Tamil Nadu – Community participation, biodiversity conservation.

Location of the Forest: The Nilgiri Biosphere Reserve, sprawling across Tamil Nadu, Karnataka, and Kerala in Southern India, is an esteemed UNESCO World Heritage site (Puyravaud & Davidar, 2013). This reserve, which includes the Nilgiri Hills and its environs, is a component of the Western Ghats, one of the world's biodiversity hotspots (Ramesh et al., 2019).

Forest Characteristics: The reserve is distinguished by its diverse topography, with mountains, grasslands, and forests, each hosting unique flora and fauna. Home to numerous endemic species, the reserve is also a crucial habitat for threatened animals like the Nilgiri tahr and Bengal tiger (Krishnakumar & Roy, 2021). The region's cultural richness further adds to its unique character.

Importance of the forests: The Nilgiri Biosphere Reserve holds significant ecological, economic, and cultural importance. Ecologically, it hosts diverse biomes that serve as important habitats for endemic and endangered species, playing a critical role in preserving global biodiversity (Krishnakumar & Roy, 2021). Economically, it provides livelihoods to local communities through sustainable tourism, agriculture, and other forest-related activities (Aram & Arul, 2017).

Concerns: Despite its importance, the reserve faces pressing threats, including deforestation and habitat fragmentation due to agricultural expansion, urban development, and climate change (Ramesh et al., 2019). This encroachment disrupts wildlife corridors, leading to increased human wildlife conflicts.

Strategies: Sustainable forest management techniques have been put into place as a reaction to these difficulties, concentrating on community involvement and biodiversity preservation. Initiatives like the Nilgiri Tahr Foundation promote community-based conservation efforts and awareness programs (Krishnakumar & Roy, 2021). The reserve's management has also prioritized establishing wildlife corridors to mitigate habitat fragmentation (Ramesh et al., 2019).

Outcomes and Success: These strategies have yielded encouraging results, with improvements in biodiversity conservation and community involvement in conservation efforts (Arul Aram & Arul, 2018; Varghese et al., 2015).

Indian case study 6: Bori Reserve Forest in Madhya Pradesh – Participatory Forest management, eco-development.

Location of the Forest: The Madhya Pradesh region of central India is where the Bori Reserve Forest first appeared. The Pachmarhi Biosphere Reserve, which also includes the Satpura National Park and the Pachmarhi Sanctuary, includes it as an important component (Bijalwan, 2017).

Forest Characteristics: This deciduous forest is characterized by a mix of bamboo and teak trees, coupled with a rich variety of flora and fauna (Véron & Fehr, 2011). It is home to diverse wildlife, including tigers, leopards, wild boars, and diverse bird species, thereby contributing to India's rich biodiversity (Samal, Mili, & Dollo, 2019).

Importance of the forests: Bori Reserve Forest is essential for multiple reasons, including biodiversity conservation, ecosystem services, and community livelihoods. It hosts a broad spectrum of species, playing a critical role in maintaining regional biodiversity (Bijalwan, 2017). Additionally, it provides beneficial ecosystem services including soil stabilisation, air and water purification, and temperature management (Samal, Mili, & Dollo, 2019).

Concerns: The Bori Reserve Forest faces challenges linked to resource overexploitation, deforestation, and wildlife poaching. Economic expansion and rapid population increase have put strain on forest resources, causing degradation and the loss of biodiversity. (Swain, 2009).

Strategies: In addressing these challenges, authorities have adopted strategies emphasizing participatory forest management and eco-development (Véron & Fehr, 2011). Joint forest management programs, participation of local people in decision-making, and forest conservation efforts are examples of initiatives.

Outcomes and Success: These initiatives have resulted in a decrease in illegal activities and improved forest health and biodiversity conservation (Véron & Fehr, 2011). The initiatives have encouraged local communities' feeling of stewardship, supporting the sustainable use of forest resources and fostering socioeconomic growth, thereby demonstrating the effectiveness of participatory approaches in forest management (Bijalwan, 2017).

Indian case study 7: Kaziranga National Park in Assam – Rhino conservation, community engagement.

Location of the Forest: The Kaziranga National Park is a well-known UNESCO World Heritage Site and is situated in the northeastern Indian state of Assam (Barbora, 2017). Acclaimed globally for its concerted efforts in rhino conservation, the park stands as a crucial emblem of community engagement and sustainable wildlife management (Hazarika & Kalita, 2019).

Forest Characteristics: The park showcases diverse ecosystems, including floodplain grasslands, tropical moist broadleaf forests, and wetlands (Barbora, 2017). It boasts a wealth of biodiversity, with notable populations of Indian rhinoceros, Bengal tigers, elephants, and wild buffaloes, among many other species. The park's distinct hydrological pattern also fosters an abundance of aquatic flora and fauna (Hussain, 2021).

Importance of the forest: Kaziranga National Park plays a vital role in regional and global ecology, economy, and culture. As a haven for several endangered species, notably the Indian rhinoceros, the park is pivotal in global biodiversity conservation efforts (Hazarika & Kalita, 2019). From an ecological perspective, it offers vital ecosystem services including water filtration and temperature management (Smadja, 2018).

Concerns: Despite these benefits, the park grapples with significant challenges, including poaching, habitat degradation, and human-wildlife conflict. Poaching of the Indian rhinoceros for its horn has been a persistent issue (Chakrabarty, Pan, & Mandal, 2019).

Strategies: The Park has undertaken a number of methods to address these problems, with a special emphasis on community involvement and rhino conservation. Strict anti-poaching measures have been put in place, as has increased monitoring (Chakrabarty, Pan, & Mandal, 2019). Authorities have also put a lot of emphasis on community-based conservation, including residents in conservation initiatives and decision-making.

Outcomes and Success: These strategies have led to notable success, evidenced by the growth in the park's rhino population and a decline in poaching incidents. Improved community engagement has resulted in more sustainable livelihoods and reduced human-wildlife conflicts (Smadja, 2018). These successes underscore the power of integrated, community-based approaches to sustainable forest management (Das & Hussain, 2016).

Indian case study 8: Kanha National Park in Madhya Pradesh – Ecodevelopment, wildlife protection.

Location of the Forest: The Madhya Pradesh state's Kanha National Park, located in the centre of India, is well known for its effective use of eco-development and animal preservation strategies (Kashwan, 2016). Kanha Park, one of India's biggest and best-managed parks, epitomises the philosophy of sustainable forest management (Banerjee, 2012).

Forest Characteristics: The park is characterized by a mix of sal and bamboo forests, meadows, and ravines. It houses a rich variety of wildlife, including the Royal Bengal Tiger, Indian leopard, and the endangered swamp deer or 'Barasingha', a species that Kanha has notably managed to save from extinction (Kashwan, 2016). The park also hosts a myriad of bird species, contributing significantly to the country's biodiversity (Panwar & Chaudhry, 2019).

Importance of the forest: Kanha National Park's importance transcends ecological bounds. The park is a biodiversity hotspot, safeguarding numerous endangered species, and serving as a living repository of genetic diversity (Banerjee, 2012). It provides a wide range of ecosystem services, including carbon sequestration, water management, and soil protection, from an ecological perspective. The park contributes substantially to regional tourism revenue, supporting local economies and promoting sustainable livelihoods. It also holds a significant cultural value, being a source of inspiration for Rudyard Kipling's renowned 'The Jungle Book' (Ahmed et al., 2012).

Concerns: The park faces challenges linked to habitat degradation, poaching, and human-wildlife conflicts. Unregulated tourism has posed threats to wildlife habitats, while the escalating demand for wildlife products propels poaching activities (Véron & Fehr, 2011). Furthermore, encroachments on forest peripheries have amplified human-wildlife conflict, leading to loss of life and property on both sides.

Strategies: To counter these challenges, Kanha authorities have adopted ecodevelopment and wildlife protection strategies. Measures include increased surveillance and stringent anti-poaching laws, along with successful relocation and rehabilitation programs for communities living within the park boundaries (Kashwan, 2016; Banerjee, 2012). The park administration has actively engaged with local communities, involving them in ecotourism activities, thus creating alternate livelihood options and reducing human dependence on the forest resources (Panwar & Chaudhry, 2019). Awareness and education programs on wildlife conservation have been pivotal in garnering public support for park's initiatives (Véron & Fehr, 2011).

Outcomes and Success: These measures have yielded positive results: reduced poaching incidents, enhanced wildlife populations, and healthier ecosystems. Successful community integration has led to decreased human-wildlife conflict and better socio-economic outcomes for local communities (Ahmed et al., 2012). Kanha National Park thus exemplifies how sustainable forest management can harmonize ecological conservation with human development (Kishnani, 2019).

Indian case study 9: Muthanga Wildlife Sanctuary in Kerala – JFM, protection of indigenous rights.

Location of the Forest: The bigger Wayanad Wildlife Sanctuary, which includes the smaller Muthanga Wildlife Sanctuary, is situated in the state of Kerala in southern India (Münster & Münster, 2012). This sanctuary is an excellent example of sustainable forest management since it employs Joint Forest Management (JFM) and upholds indigenous rights (Nithya, 2014).

Forest Characteristics: Muthanga is characterised by moist deciduous forests, with teak, Maruthi, karimaruthi, rosewood, and even teak as its dominant flora (Münster & Münster, 2012). It is home to diverse fauna, including elephants, tigers, panthers, and various species of deer. Its geographic location within the Nilgiri Biosphere Reserve enhances its unique biodiversity, making it a crucial wildlife corridor (Pradheeps, 2014).

Importance of the forest: The cornerstone of ecological, social, and cultural importance is the Muthanga Wildlife Sanctuary. It is an essential component of the Nilgiri Biosphere Reserve from an ecological standpoint, offering a variety of ecosystem services, including water purification, carbon sequestration, and habitat supply for a number of rare and endangered species (Anti-capitalist, 2022). The sanctuary plays an essential role in regional tourism, supporting local economies and providing educational experiences (Sathyapalan & Reddy, 2010).

Concerns: Muthanga faces challenges linked to deforestation, illegal poaching, and encroachments into the forest for agriculture and settlement purposes (Anti-capitalist, 2022). Disputes over land and forest rights, particularly those of indigenous communities, have created social tensions and conflicts. A key danger to the unique biodiversity of the forest and the survival of the indigenous tribes is climate change, which causes changes in rainfall patterns and an increase in the risk of forest fires (Münster & Münster, 2012).

Strategies: To address these concerns, Muthanga has adopted JFM and strategies to protect indigenous rights. A feeling of ownership and sustainable use of forest resources are promoted through JFM, which incorporates local people in forest management choices (Sathyapalan & Reddy, 2010).

Outcomes and Success: These strategies have resulted in positive outcomes, including decreased deforestation, better preservation of biodiversity, and improved social equity (Pradheeps, 2014). Successful implementation of JFM has empowered local communities, mitigated conflicts, and promoted sustainable use of forest resources, reflecting the success of combining conservation efforts with social justice (Anti-capitalist, 2022).

Indian case study 10: Sariska Tiger Reserve in Rajasthan – Wildlife conservation, ecotourism.

Location of the Forest: Sariska Tiger Reserve, a model of sustainable ecotourism and animal protection, is situated in the Alwar district of Rajasthan, India (Kumar et al., 2020). This 866 square kilometre reserve was first designated as a wildlife sanctuary in 1955, and in 1978 it was included to India's Project Tiger reserves (Jain & Sajjad, 2016).

Forest Characteristics: Dry deciduous woods, scrub-thorn desert forests, boulders, and grasses are what define Sariska. Numerous animals and plants may be found there, including the Bengal tiger, Indian leopard, sambar, chital, and more than 200 different types of birds. Its historic sites, such as the Kankwari Fort, further add to its unique charm (Kumar et al., 2020).

Importance of the forests: Sariska Tiger Reserve is important from ecological, economic, and cultural perspectives. In terms of ecology, it operates as a biodiversity hotspot, providing essential ecosystem services like carbon storage, water filtering, and soil conservation, as well as crucial habitats for threatened animals like the Bengal tiger (Sharma et al., 2013; Torri, 2011).

Concerns: However, Sariska has grappled with severe threats such as deforestation, poaching, and anthropogenic pressures causing habitat fragmentation. The dwindling tiger population due to poaching emerged as a critical concern, leading to the shocking revelation in 2004 that no tigers were left in the reserve (Sharma et al., 2013). Additionally, increased tourism pressure, illegal mining activities, and conflicts between wildlife and local communities exacerbate these challenges (Jain & Sajjad, 2016).

Strategies: As a result, several sustainable forest management techniques have been used. These include strict anti-poaching measures, habitat improvement programs, and the translocation of tigers to replenish the population (Jain & Sajjad, 2016). Community-based ecotourism has been promoted, encouraging responsible tourism and local involvement (Sharma et al., 2013).

Outcomes and Success: These strategies have witnessed significant successes. The tiger population has recovered through translocation efforts, ecotourism has boosted the local economy and awareness, and human-wildlife conflicts have been reduced. Overall, Sariska serves as a representation of tenacity and a case study of effective sustainable forest management (Sharma et al., 2013a).

4.10 Conclusion

The role of institutions in sustainable forest management (SFM) in India reveals that institutions play pivotal roles across various aspects, from policy formulation to community engagement and research (Sheppard et al., 2020; Maginnis and Sayer, 2013; Singh, 2013; Dyer et al., 2014).

Institutions foster policy directions, govern forest conservation efforts, and champion research and education that further underpin SFM (Coleman and Mwangi, 2013; Jhariya, Banerjee, Meena, and Yadav, 2019). The political and legal landscape significantly affects SFM in India (Divan and Rosencranz, 2022; Edmunds and Wollenberg, 2013). Legislation, political decision-making, and judiciary interpretations can either enhance or hinder SFM efforts, emphasizing the importance of aligned legal provisions and proactive governance (Cronkleton, Pulhin, and Saigal, 2012).

Broadly, while the central institutes has the responsibility of determining the overall policy frame, the sub-national institutes are mainly involved in implementation. Thus, this system attempts to minimize transaction costs by providing sufficient scope for decentralized governance of forests. At the same time, the central government has overriding powers to avoid unstable competition and institute mechanisms to resolve inter-state disputes. The institutions of JFM and village forest committees have enhanced the stake of the local population in the development of forestry.

Different levels of government, from national to state and local, influence SFM in distinctive ways (Springate-Baginski and Blaikie, 2013; Cheng et al., 2019). Their roles, limitations, and success stories reflect the complex governance structure that navigates India's diverse forest landscapes (Nagendra and Ostrom, 2012; Gupta, 2014).

One of the common assumptions made about decentralization is that encouraging local participation, and more equitable sharing of benefits from forest management at the local level, will foster more sustainable use and management of forest resources. Although there are many cases of forests being better protected or rehabilitated after handover to local control and management (for example case studies presented above), decentralization of forest management can also lead to ecologically unsustainable outcomes and the need for capacity building and development of technical skills are critically important. The decentralization of forest management stands out as a significant development (Colfer and Capistrano, 2012). Although decentralization has brought forth challenges, it has also presented opportunities to empower local communities and evolve institutional capabilities (Lund, Rutt, and Ribot, 2018; Gupta, 2014).

Summary of the chapter

Managing forests in India involves navigating numerous complexities arising from the multiple, often competing, and stakeholders' interests. Conflicts occur between conservation objectives and the livelihood needs of forest-dependent communities. Previous chapter of the thesis already show that the impact of infrastructural development, agricultural expansion, and climate change on forest landscapes further complicates the situation. In addition, implementing forest rights and ensuring participation of indigenous communities in forest management remains challenging (Chazdon et al., 2016).

These complexities underscore the need for a more integrated and participatory approach to forest management in India. The chapter offers a comprehensive understanding of the institutional landscape in forest management in India. The theoretical framework is adapted from IAD (Institutional analysis and development) framework developed by (Ostrom et al. 1994). The chapter explores the institutional framework (central, state and local level) along with their key roles and contributions.

The formal and informal mechanisms for co-ordination amongst different institutes at different level of operations are explored in the chapter. This includes NFP (National Forest Policy), National wildlife action plan (NWAP), JFM (Joint Forest Management) etc. The informal mechanism present in the forest governance system includes partnerships between NGOs and government agencies and different networks between forest officials, researchers, conservationists, NGOs and government agencies. This is supplemented by case studies of effective collaboration.

The chapter then address the role of institutes in sustainable forest management. One of the main insights of the chapter concludes that India still lacks a balance between roles of judiciary, the rights of local communities and sustainable development goals. The institutes at different levels of governance contribute in sustainable forest management with different strategies and policies according to the respective case and its requirement as shown by ten case studies mentioned in the chapter from across India. The case studies are crucial part of the chapter to understand different challenges and the scale of implementation across the country. The different strategies mentioned in the case studies can be taken as examples to be mixed and match for different scenarios in attaining sustainable forest management. The chapter discusses the importance and challenges of decentralization and institutional evolution post decentralization. The main take away from this chapter is to understand that the role of institutions in sustainable forest management (SFM) in India is critical. It reveals that institutions play pivotal roles across various aspects, from policy formulation to community engagement and research (Sheppard et al., 2020; Maginnis and Sayer, 2013; Singh, 2013; Dyer et al., 2014). The political and legal landscape significantly affects SFM in India (Divan and Rosencranz, 2022; Edmunds and Wollenberg, 2013). Broadly, while the central institutes has the responsibility of determining the overall policy frame, the sub-national institutes are mainly involved in implementation.

At the same time, the central government has overriding powers to avoid unstable competition and institute mechanisms to resolve inter-state disputes. The institutions of JFM and village forest committees have enhanced the stake of the local population in the development of forestry. However, decentralized solutions may also lead to power shifts to the elite group unless adequate safeguards are taken. Decentralization of forest management can also lead to ecologically unsustainable outcomes and the need for capacity building and development of technical skills are critically important. The decentralization of forest management stands out as a significant development (Colfer and Capistrano, 2012). Although decentralization has brought forth challenges, it has also presented opportunities to empower local communities and evolve institutional capabilities (Lund, Rutt, and Ribot, 2018; Gupta, 2014).

Chapter 5: Synergies between forestry and sustainable development goals: Identifying effective actions.

5.1 Introduction

In 2015, the 2030 sustainable development agenda was introduced by the United Nations in partnership with its member states. The comprehensive initiative consisted of a set of 17 sustainable development goals (SDGs) and 169 associated targets, with the objective of fostering economic well-being while simultaneously safeguarding the environment. The Sustainable Development Goals (SDGs) encompass a comprehensive and inclusive appeal to address poverty eradication, enhance healthcare and education, mitigate inequality, foster economic advancement, tackle climate change, and safeguard marine and forest ecosystems (Andersson, 2018). Economic sustainability aims to foster growth and development without exhausting natural resources (Malik, Awasthi, and Sinha, 2020). Social sustainability focuses on creating an equitable society that meets basic human needs and preserves human rights. Ecological sustainability emphasises the preservation and enhancement of environmental resources (Katila et al., 2019).

Against this backdrop, Indian forestry has demonstrated a strategic integration of SDGs into its forest management practices. India, being one of the 193 countries committed to achieving SDGs, recognizes forests' significant role in fulfilling several of these goals, particularly those concerning climate change, life on land, and poverty reduction (Barik and Mishra, 2008). Under the umbrella of these commitments, the Indian forestry sector has made deliberate strides in aligning its strategies and policies with the SDGs. For instance, community-based forest management programs in India have adopted practices aimed at economic and social sustainability (Bhattacharya, Pradhan, and Yadav, 2010).

Numerous studies have examined the Sustainable Development Goals (SDGs) and forest management separately. However, there remains a marked dearth of research investigating the synergy between the SDGs and Indian forest management within a consolidated theoretical framework (Barik and Mishra, 2008; Katila et al., 2019). This gap is significant because the intricacies of this synergy are not only relevant for policymaking and planning but also vital for evaluating progress toward sustainability targets.

This fragmented approach fails to capture the entirety of the symbiotic relationship between SDGs and Indian forestry. For example, how do social, economic, and ecological sustainability, which are the core themes of SDGs, interlink with Indian forestry strategies and initiatives at a broader level? What are the synergies and trade-offs involved? Such questions remain largely unanswered (Jattan, 2003). Moreover, without a holistic theoretical framework, it becomes challenging to measure and assess the overall impact of Indian forestry practices on SDG achievement. As Lal and Singh (2003) argue, the lack of a systematic approach limits the ability to track progress, identify gaps, and make necessary adjustments in forest management to ensure that it contributes effectively to the SDGs.

The scarcity of theoretical studies also inhibits the development of forest-related policies and strategies that are well-aligned with the SDGs. Comprehensive research could provide valuable insights into the potential of Indian forestry as a tool for achieving SDGs, thereby helping policymakers to refine their strategies and allocate resources more effectively (Andersson, 2018).

5.2 Theoretical framework

The Sustainable Livelihoods Framework (SLF) is a comprehensive and multifaceted conceptual framework that was formulated with the aim of enhancing our comprehension of livelihoods, specifically those of individuals living in poverty (Natarajan et al., 2022). According to Levine (2022), this framework offers a conceptual approach to understanding the well-being of individuals who are facing poverty and disadvantage. Additionally, it functions as a valuable instrument for directing consistent policy development and implementation. According to Lescuyer (2013), there is a compelling argument for the application of the Sustainable Livelihoods Framework (SLF) in order to demonstrate the interconnectedness between forest management in India and the achievement of Sustainable Development Goals (SDGs).

A range of studies (such as Kabonga, 2020; Zenteno et al., 2013) noted that the SLF is not a model to be applied rigidly but a flexible tool that should be adapted to the local context. It's an approach that helps to identify where interventions might be most effective and provides a way of thinking about how different factors and policies interact to affect people's livelihoods.

This research has developed a new theoretical framework called 'Adapted Sustainable Livelihoods Framework (ASLF)' that incorporates elements from the Sustainable Livelihoods Framework (SLF), Ecosystem Services Framework (ESF), and Natural Capital Theory. The 'Adapted Sustainable Livelihoods Framework (ASLF) is demonstrated below.

Figure 5.1: Adapted Sustainable Livelihood Framework

5.2.1. Livelihood Assets and Sustainable Forest Development Outcomes

The idea of "Livelihood Assets," which is one of the pillars of the presented theoretical framework (ASLF) plays an important part in the way that forest management in India contributes to the achievement of sustainable development objectives. It offers a sophisticated and multifaceted view of what people, families, or communities do have, as opposed to what they do not have (Natarajan et al., 2022). There are five distinct kinds of livelihood assets, which may be broken down into their respective categories as follows: human, natural, financial, physical, and social capital. Each of these forms of capital plays a distinct part in the development process.

The influence of human capital on forest management is directly linked to an individual's abilities, knowledge, labor capacity, and health status. Pandey et al. (2017) assert that forest-dependent communities in India possess a substantial body of traditional knowledge pertaining to the governance and preservation of forest ecosystems. This phenomenon can be attributed to their close association with forest ecosystems. In contrast, the term "natural capital" is used to denote the collection of natural resources and environmental services that are utilized in the production of goods and services for human consumption. The forests play a crucial role in the overall capital by offering a diverse array of commodities and benefits, such as timber, non-timber forest products, and ecosystem services like carbon sequestration and water purification (Lescuyer, 2013).

The term "financial capital" refers to the monetary resources that are used in the pursuit of living goals. According to Pandey et al. (2017), sustainable forest management practices have the potential to create revenue for local communities. Roads, water systems, power grids, and medical and educational facilities all fall under the category of "physical capital," and all are crucial to people's ability to earn a living. Infrastructure such as forest roads and facilities for processing forest products may help enhance the efficacy and sustainability of livelihoods associated to forests (Pasanchay & Schott, 2021). This is true in the context of forest management.

The Livelihood Assets not only contribute to the sustainable management of forests, but they are also closely linked to the Sustainable Development Goals (SDGs). Sustainable Development Goal 1, which aims to eradicate poverty, and Sustainable Development Goal 8, which focuses on promoting decent work and economic growth, are interconnected in their pursuit of enhancing financial capital through the sustainable management of forests. Similarly, the association between Sustainable Development Goal 4, which pertains to Quality Education, and Sustainable Development Goal 3, which focuses on Good Health and Well-being, can be observed in relation to human capital.

5.2.2 Ecosystem Services and Sustainable Forest Development Outcomes

The phrase "ecosystem services" was used by Pottschin et al. (2016) to describe the positive effects ecosystems have on people's lives. The Ecosystem Services Framework (ESF) provides the following definition. In the context of forest management in India, ecosystem services contribute significantly to the outcomes of sustainable development due to their various social, economic, and environmental benefits. Wood and products derived from non-timber forest products are examples of forest-provided commodities and services that are crucial to the economic stability of many rural communities. For many indigenous communities in India, gathering and selling no timber forest products is a crucial economic activity (Lele, 2013).

The provision of many cultural services, such as spiritual enlightenment, intellectual growth, and recreational opportunities, is also an important aspect of what woods provide. According to Abolina and Luzadis (2013), several kinds of wood in India are regarded as holy and play an important part in the cultural and spiritual practices of the local inhabitants.

The examination of the relationship between ecosystem services and the Sustainable Development Goals (SDGs) reveals the notable importance of ecosystem services in facilitating the attainment of sustainable development objectives in forest management. The provisioning services provided by forests are closely linked to Sustainable Development Goal 1 (No Poverty), Sustainable Development Goal 2 (Zero Hunger), and Sustainable Development Goal 8 (Decent Work and

Economic Growth). On the other hand, the regulating services offered by forests play a significant role in supporting Sustainable Development Goal 13 (Climate Action), Sustainable Development Goal 6 (Clean Water and Sanitation), and Sustainable Development Goal 15 (Life on Land). The cultural services provided by forests are associated with both Sustainable Development Goal 3, which focuses on promoting good health and well-being, and Sustainable Development Goal 11, which aims to foster sustainable cities and communities (Spangenberg, von Haaren, & Settele, 2014; Feng et al., 2018).

5.2.3 Vulnerability context and its influence on synergies between SDGs and sustainable forest management in India.

The Vulnerability Context, which is a crucial component of the theoretical framework, plays a pivotal role in comprehending the interplay between the Sustainable Development Goals (SDGs) and the sustainable management of forests in India. The context encompasses various factors such as external shocks, seasonality, and longer-term trends that have a direct influence on livelihoods and the sustainable utilization of forest resources (Pasanchay & Schott, 2021).

The health and productivity of forests can be substantially influenced by exogenous disturbances, including but not limited to forest fires, pest infestations, and extreme weather phenomena (Pandey, Tripathi, and Kumar, 2016). The disruptions mentioned can lead to sudden and negative outcomes, impacting not only the economic well-being of communities reliant on forests but also the delivery of ecosystem services (Pasanchay & Schott, 2021). Seasonal changes also influence the availability of forest resources and can have significant implications for forest-dependent livelihoods. For instance, variations in the collection season of non-timber forest products can affect income and food security among forest-dependent communities (Ferguson & Chandrasekharan, 2012). Longer-term trends, including climate change and population growth, pose considerable challenges to the sustainability of forest resources. These trends can intensify pressures on forests, leading to degradation and loss of biodiversity (Dent, Dubois, & DalalClayton, 2013).

The Vulnerability Context assumes a pivotal role in fostering the interplay between Sustainable Development Goals (SDGs) and the practice of sustainable forest management in the Indian context. By comprehending and mitigating vulnerability, the practice of forest management can enhance its alignment with multiple Sustainable Development Goals (SDGs). One potential means of advancing SDG 1 (No Poverty) is through the implementation of forest management strategies that are responsive to external shocks and seasonal variations. This approach can effectively enhance the stability of the livelihoods of communities reliant on forest resources. The implementation of forest management strategies that effectively address the consequences of enduring phenomena like climate change is consistent with the objectives outlined in Sustainable Development Goal 13 (Climate Action). Similarly, the preservation of biodiversity and the promotion of forest well-being are in line with the aims of Sustainable Development Goal 15 (Life on Land) (Scoones, 2015).

5.2.4 Forest Management Practices and how it is impacted by SDGs and sustainable forest management in India.

Forest management practices refer to the various approaches humans employ to engage with, use, and oversee forest ecosystems. The impact of the Sustainable Development Goals (SDGs) on these practices within the Indian context can manifest in both direct and indirect ways, resulting in substantial effects on the broader forest management system.

Sustainable Development Goal 15, commonly known as "Life on Land," holds significant importance as it directly impacts the implementation of forest management strategies. The primary objective is to safeguard, rehabilitate, and advance the sustainable utilization of terrestrial ecosystems, effectively administer forests in a manner that ensures their long-term viability, counteract the process of desertification, cease and reverse the deterioration of land quality, and put an end to the decline in biodiversity (Feng et al., 2018).

The promotion of sustainable forest management within Sustainable Development Goal 15 places significant importance on the incorporation of ecological factors into forest management strategies. This includes the preservation of biodiversity, safeguarding of watersheds, and the conservation of soil fertility. The aforementioned practices not only make a positive contribution towards achieving Sustainable Development Goal 15, but they also demonstrate alignment with other Sustainable Development Goals, namely Goal 6 (Clean Water and Sanitation), Goal 13 (Climate Action), and Goal 14 (Life Below Water). This highlights the interconnected nature of the Sustainable Development Goals and underscores the manifold advantages of implementing sustainable forest management practices (Rametsteiner & Sotirov, 2015).

Furthermore, the SDGs, specifically SDG 1 (Eradicating Poverty), SDG 2 (Eliminating Hunger), and SDG 5 (Advancing Gender Equality), encompass principles of social equity and inclusivity that facilitate alterations in forest management methodologies. The aforementioned modifications aim to promote a shift towards a management approach that is more participatory and community based. This approach entails the active engagement of local and indigenous populations, including women, in the process of decision-making (Spangenberg, von Haaren, & Settele, 2014). These practices not only facilitate the advancement of social equity but also frequently result in improved and more enduring outcomes. This is because they harness local knowledge and secure the support of individuals who are most directly impacted by decisions related to forest management (Nichiforel et al., 2021).

5.2.5 Livelihood Strategies and the synergy with SDGs and sustainable forest management in India

Livelihood strategies refer to the deliberate choices and organization of activities pursued by households or individuals in order to maintain or enhance their living standards (Chen et al., 2013). Several communities in India, whose economic well-being is closely tied to forests, employ various strategies centered on the utilization of forest resources to meet their basic needs and generate income. These approaches often involve the procurement and commercialization of nontimber forest products (NTFPs), which include medicinal plants, fruits, nuts, and resins. Additionally, they may also involve small-scale timber extraction and agroforestry practices (Deal, Cochran, & LaRocco, 2012).

If the implementation and governance of sustainable forest management practices are carried out effectively, they possess the capacity to bolster these livelihood strategies by guaranteeing the enduring viability of the resources on which they depend. One potential strategy for empowering local communities to exercise effective governance over and sustainably utilize forest resources is through the implementation of community-based forest management. The implementation of this practice holds the capacity to enhance the security of individuals' means of subsistence and provide significant contributions towards the realization of Sustainable Development Goals 1 (Eradicating Poverty) and 2 (Eliminating Hunger) (Salmanicheraghabadi et al., 2021).

Trees provide two additional ecosystem services that are crucial for agricultural operations: the supply of clean water and the management of regional temperature (Fenichel & Abbott, 2014).

These services provide indirect support to livelihood strategies. The implementation of sustainable forest management is of considerable importance in facilitating livelihood strategies that are based on agriculture, thus demonstrating its alignment with the objectives articulated in SDG 2 (Zero Hunger) and SDG 6 (Clean Water and Sanitation) (Raven, 2012).

5.3 Methodology

This study leverages a Systematic Literature Review (SLR) as the research methodology to delve into the synergy between Sustainable Development Goals (SDGs) and Indian Forest Management. The concept of a Systematic Literature Review, as detailed by Xiao and Watson (2019), hinges on the premise of providing a replicable, scientific, and transparent approach, covering a broad field of research.

The adoption of an SLR for this study is justified for several reasons. First, given the complexity and interdisciplinary of the research theme, an SLR allows for the synthesis of evidence from a diverse range of studies, ensuring a comprehensive understanding of the topic (Cocchia, 2014; Zhang et al., 2021). Furthermore, the structured and systematic nature of an SLR ensures objectivity, reducing the risk of bias and facilitating the identification of research gaps (Hinz et al., 2020). This is particularly important for our research aim, which seeks to not only identify the key SDGs relevant to Indian Forest Management but also provide recommendations for policy reforms. In this context, the SLR will help scrutinise the existing body of knowledge, evaluating the role of institutions in sustainable forest management (Katila et al., 2019), examining the current policies and strategies of Indian Forest Management in light of SDGs (Surana, Singh, & Sagar, 2020), and offering an opportunity to analyse the dynamics of SDGs implementation in Indian forest management (Poddar, Narula, & Zutshi, 2019).

Exclusion and inclusion criteria are crucial components of a Systematic Literature Review (SLR) as they help determine which studies are relevant for inclusion in the review (Tolliver, Keeley, and Managi, 2019; Opoku, 2019). These criteria are defined at the onset of the review to streamline the process of selecting articles and to ensure consistency and objectivity (Leal Filho et al., 2019). Inclusion criteria are features or characteristics that a study must possess to be included in the review, whereas exclusion criteria are features that would result in a study's dismissal.

The importance of robust inclusion and exclusion criteria for this study cannot be understated. It ensures the extraction of the most relevant and quality literature pertaining to SDGs and Indian

Forest Management, providing an objective and comprehensive understanding of the subject matter (Smith et al., 2019; Islam and Managi, 2019).

The inclusion and exclusion criteria for the current study are presented below:

Subjects	***Inclusion criteria***	***Exclusion criteria***
Research Database	The journal articles that are published in the following: • Elsevier • ScienceDirect • Sage Journals • Springer Link • National Mission for Clean Ganga • National Health Mission • Smart Cities • National Water Development Agency	The journal articles that have been published in journals and database beyond the mentioned publishers.
Resource type	Academic Journal articles.	Journal articles that are non-academic such as conference papers.
	Database search terms	
Theme Number	***Inclusion terms***	***Exclusion terms***
Database search limiters	Only peer-reviewed Journal Articles	Journals that are not peer-reviewed.
Search Terms	SDGs, Indian Forestry, Sustainable Forestry India.	Something that is not related to the chosen keywords.
Timeframe of resources	• Mainly 2010 to 2022 • Will also include a few from 2008 to 2009 if found highly relevant	• Journal articles that have been published before 2008.
Case study firm nature	• Must be about Indian forestry	• Cases that are not from Indian forestry.

Table 5.1: The inclusion and exclusion criteria for the current study

Following the inclusion and exclusion criteria stated above, the current study has selected 81 studies in the SLR process. How the study has selected 81 studies can be found on the figure 5.2 below.

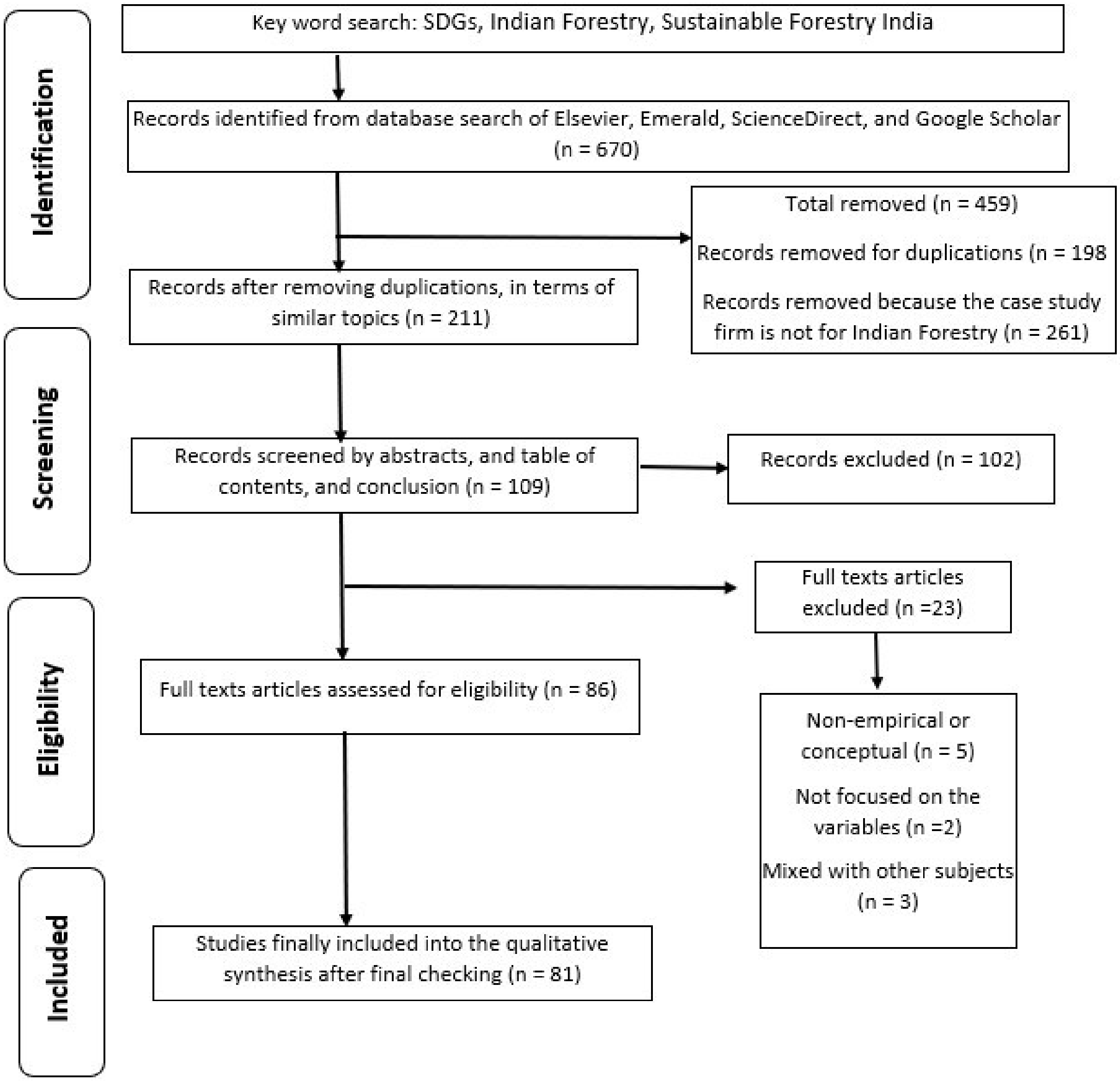

Figure 5.2: Methodology process

Source: Adapted from Xiao and Watson, 2019

5.4 Analysis and discussion

SDG 1: No Poverty

The research findings suggest that forestry plays a substantial role in mitigating poverty in India. According to a survey conducted by the Forest Survey of India in 2019, the forestry land in India spans an area of 80.9 million hectares, serving as a vital resource for an estimated population of around 300 million individuals who live in close proximity to these forests. These individuals rely either directly or indirectly on the revenue generated from activities associated with forestry. Furthermore, the study conducted by Kumar and Saikia (2020) revealed that agriculture, in 2019, accounted for approximately 17%. This finding underscores the notable economic significance of this sector, which has consistently contributed to India's GDP for three consecutive years prior to 2019. Upon analysis of these findings, it becomes apparent that the forestry sector in India plays a pivotal role in sustaining the livelihoods of a substantial portion of the populace, particularly those residing in rural regions (Ahmad, 2011; Akinyi, Karanja, and Hartunian, 2021).

This is consistent with Sustainable Development Goal 1, which aims to eliminate poverty, particularly through target 1.1 to eradicate extreme poverty and target 1.5 to enhance the resilience of individuals living in poverty and vulnerable circumstances to climate-related extreme events, as well as other economic, social, and environmental shocks (Amezaga et al., 2019; Koskela et al., 2014). Forestry serves as a means of mitigating vulnerabilities by providing a reliable and consistent source of income while also fostering resilience through the diversification of resources. In addition, the forestry sector's noteworthy impact on the gross domestic product (GDP) implies that it plays a crucial role in fostering both economic expansion and the pursuit of sustainable development (Krause and Tilker, 2021).

The integral role of forests in India's national economy is highlighted by the substantial quantity of timber they provide. Kumar (2008) notes that India is home to approximately 35 billion trees, indicating the potential for considerable timber production. Additionally, forests offer an array of non-timber forest products (NTFPs), including wild plants, fungi, wild fruits, nuts, edible roots, and small mammals. These NTFPs play a critical role in the national economy and local livelihoods in India (Lal and Singh, 2003; Malyadri, 2020).

Upon careful examination of these findings, it becomes evident that the utilization of timber and non-timber forest products (NTFPs) significantly contributes to the economic value derived from forests. Consequently, this has a direct influence on livelihoods and poverty levels. The authors Martin (2019) and Larson et al. (2016) underscore the considerable importance of timber and no timber forest products (NTFPs) in bolstering rural income and maintaining the viability of local economies. Forest products offer a diverse range of income-generating opportunities that effectively mitigate poverty, thereby making a significant contribution towards the achievement of Sustainable Development Goal 1.

The aforementioned results are in accordance with the objectives outlined in Target 1.1 of Sustainable Development Goal 1, which endeavors to eliminate extreme poverty, as well as Target 1.2, which strives to decrease by at least 50% the percentage of individuals, regardless of age or gender, residing in poverty in all its manifestations as defined by national standards. The contribution of timber and non-timber forest products (NTFPs) to income generation and livelihood diversification is particularly significant for individuals residing in impoverished and rural regions (Lele et al., 2020; Malik and Dhanda, 2003).

Moreover, the aforementioned discoveries make a valuable contribution towards the achievement of target 1.4 of Sustainable Development Goal 1. This target specifically endeavors to guarantee equitable access to economic resources, basic services, land ownership, control over property, and natural resources for all individuals, with a particular focus on impoverished and vulnerable populations. According to Malik, Awasthi, and Sinha (2020), the presence of timber and nontimber forest products (NTFPs) offers valuable economic resources to these susceptible populations, thereby aiding in the attainment of this objective (Kumar et al., 2000; Kumar and Saikia, 2020).

We can contextualize these findings, in figure 3 below, based on Adapted Sustainable Livelihoods Framework (ASLF) that we developed in the part of theoretical development (Kabonga 2020; Zenteno et al., 2013; Chen et al., 2013).

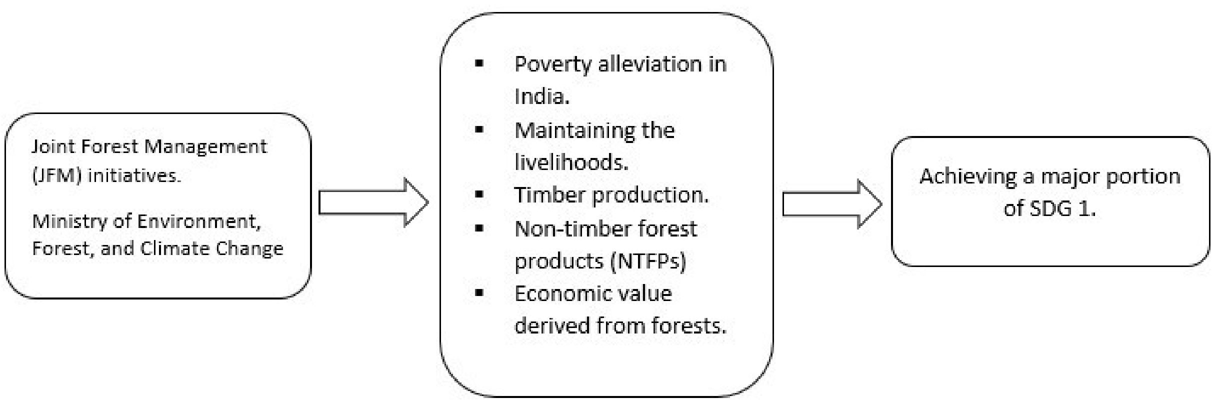

Figure 5.3: The synergy between SDG 1, forestry in India and poverty alleviation.

SDG 2: Zero hunger

The study conducted by Arora-Jonsson et al. (2019) revealed that forests play a substantial role in enhancing food security and nutrition within the context of India. Non-timber forest Products

(NTFPs), encompassing a range of wild foods obtained from forestry such as wild rice, honey, bamboo shoots, small wild animals, and wild fruits, play a crucial role in providing sustenance and nutritional advantages to communities residing in forested areas. Ashutosh and Roy (2021) underscored the significance of forests in ensuring consistent food security for populations residing in tropical forest regions of India.

These scenarios contribute to achieving SDG 2, particularly targets 2.1 and 2.2. SDG 2.1 aims for universal access to safe, nutritious, and sufficient food all year round. Forests, as reservoirs of NTFPs, provide such access to many vulnerable communities in India (McDermott et al., 2019; Minakshi, 2019). Meanwhile, SDG 2.2 targets the eradication of all forms of malnutrition. With a variety of wild foods available from forests, these ecosystems contribute to a diverse diet, helping combat malnutrition (Miller, Mansourian, and Cheek, 2020). The synergy between SDG 2 and Indian forest management is apparent.

The Indian Council of Forestry Research and Education (ICFRE) is instrumental in facilitating the preservation and enhancement of genetic resources found within the forests of India, as highlighted by Mitra (2020). This initiative presents a number of advantages. The augmentation of genetic diversity within forest resources serves to fortify the resilience of the ecosystem, thereby guaranteeing a sustainable provision of nourishment and other forest-based commodities to the neighboring communities (Asprilla-Perea and Díaz-Puente). The aforementioned statement is a direct contribution to the achievement of Sustainable Development Goal 2.4. This particular goal focuses on the establishment of sustainable food production systems and the adoption of resilient agricultural practices (Andersson, 2018; Forsell et al., 2016).

The findings found above are in line with the theoretical framework 'Adapted Sustainable Livelihoods Framework (ASLF)’ because Indian forestry provides Ecosystem Services and sustainable forest development outcomes (Lele, 2013; Pueyo-Ros, 2018). Figure 5.4 depicts the synergy.

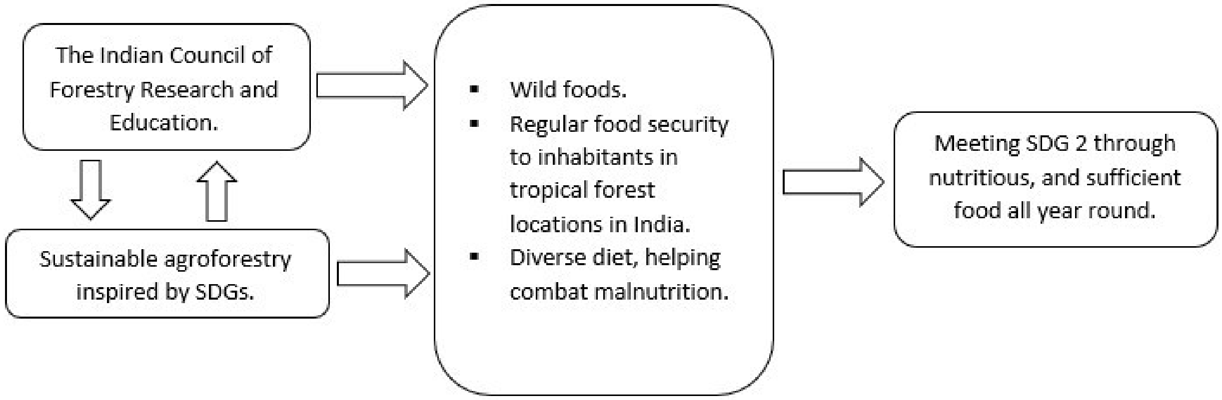

Figure 5.4: The synergy between SDG 2, Zero hunger and sustainable forestry in India

SDG 3: Good health and well-being

A study by Diduck, Patel, and Malik (2021) revealed that forests are crucial in promoting positive health benefits and reducing negative health impacts. They serve as natural filters, absorbing pollutants, and releasing oxygen, thereby enhancing air quality. Improved air quality aids in reducing the occurrence of respiratory conditions, contributing to SDG 3.4, which addresses the prevention of non-communicable diseases (Friess et al., 2019; Hazarika and Jandl, 2019). Nontimber forest products (NTFPs) also provide a vast range of medicinal products essential for the treatment of adults and children (Dlamini, 2020). For example, traditional Indian medicine systems such as Ayurveda, Unani, Siddha, and Homeopathy utilize an estimated 90,000 species of forest products, with over 90% of these coming from the wild (Prakash and Reddy, 2020). These medicinal resources from forests contribute to SDG 3.8, which advocates for access to safe, effective, and affordable essential medicines for all.

The synergy between sustainable forestry and the objectives of SDG 3 is evident in the above scenarios. Forests' health benefits are only sustainable if the forests themselves are sustainably managed. For example, overexploitation of medicinal plants could lead to their extinction, thereby reducing the availability of essential medicines (Pali et al., 2020). Therefore, sustainable forestry practices that ensure the conservation and sustainable use of medicinal plants contribute directly to achieving the SDG 3.8 target. In addition, sustainable forestry practices help mitigate climate change by acting as carbon sinks, absorbing CO2 from the atmosphere (National Mission for Clean

Ganga, 2016). This has a direct positive impact on human health as climate change is associated with an increased prevalence of diseases such as malaria and dengue fever (SDG 3.3) and heat related illnesses and mortality (SDG 3.2) (Pahuja et al., 2020).

According to research findings by Dlamini (2020), the National Medicinal Plants Board in India has implemented the Central Sector Scheme, designed to develop, sustain, and manage medicinal plants in forests. This initiative, in essence, reflects an attempt at sustainable forest management, focusing on preserving biodiversity and ensuring the continued availability of valuable medicinal resources. Such steps directly align with SDG 3.8, emphasizing universal access to safe, effective, quality, and affordable essential medicines (Ghosh-Jerath et al., 2021). Additionally, the Forest Rights Act of 2005 in India provides capacity-building training programs to local forest communities. As suggested by Diduck, Patel, and Malik (2021), this training enhances skills in collecting medicinal forest products, offering a dual advantage. First, it promotes sustainable harvesting practices, minimizing detrimental impacts on the ecosystem and safeguarding biodiversity (Friess et al., 2019). Second, it enhances local community health by ensuring continued access to traditional medicinal resources, contributing towards SDG 3 targets (Pahuja et al., 2020).

The findings above are in accordance with the sub-theme 'Vulnerability Context and How the Synergy between SDGs and sustainable forest management in India' under the developed framework: "Adapted Sustainable Livelihoods Framework (ASLF)" (Natarajan et al., 2022; Kabonga 2020; Zenteno et al., 2013). The synergy between forestry in India and the synergy of SDG 3 can be depicted in Figure 5.5 below:

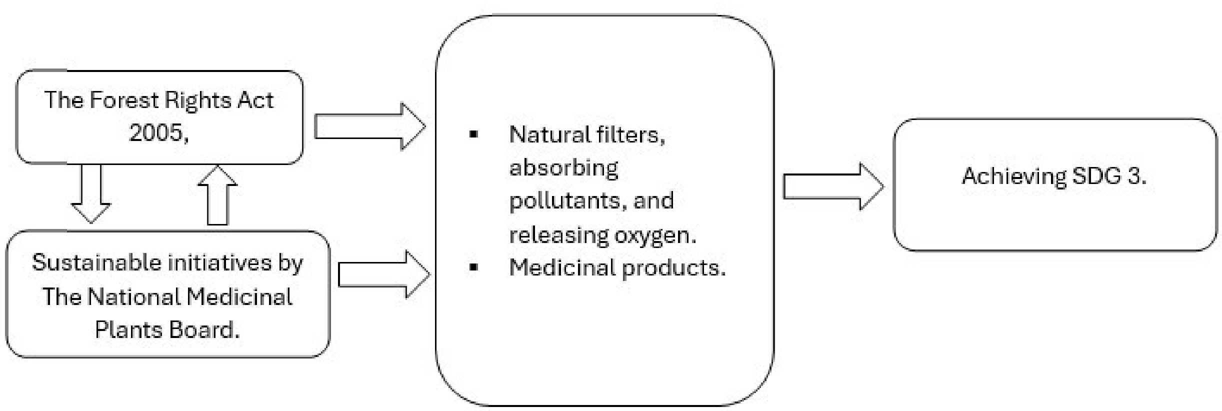

Figure 5.5: The synergy between forestry in India and synergy of SDG 3

SDG 4: Quality education

Pro-environmental behaviour, according to Tomaselli et al. (2019), encompasses attitudes, actions, and policies that respect and contribute to the well-being of the environment. This perspective is intrinsically linked to mitigating the negative impacts of human activities on the climate and both natural and built environments. For example, individuals practising pro-environmental behaviours might adopt sustainable consumption patterns, reducing waste and energy usage (Humphreys et al., 2019).

In India, the importance of nurturing pro-environmental behaviour through education is wellrecognised. One noteworthy initiative is the Rajiv Gandhi National Fellowship for tribal students. Prasad and Alizadeh (2020) highlight that this fellowship not only provides financial support for students in forest and wilderness areas but also instils a deep sense of environmental responsibility. By granting students direct exposure to forest ecosystems, the fellowship promotes an understanding of the delicate balance within these habitats and the necessity of sustainable practices (Neelakantan et al., 2020; Nautiyal, Smitha, and Kaechele).

The aforementioned initiatives and scenarios have substantial implications in the achievement of the targets outlined in Sustainable Development Goal 4, which pertains to the provision of quality education. An example of this can be seen in the Rajiv Gandhi National Fellowship, which specifically corresponds to Target 4.5. This target seeks to address gender inequalities in education and promote equitable access to education at all levels for marginalised communities (Patel, Sharma, and Singh, 2020). This initiative aims to address educational disparities by providing support to students residing in forest and wilderness areas, with a particular focus on vulnerable populations.

The emphasis on pro-environmental behaviour in these initiatives speaks directly to Target 4.7, which stresses the importance of education for sustainable development and sustainable lifestyles (Tomaselli et al., 2019; Jagger et al., 2019; Jattan, 2003). In essence, these initiatives foster a sense of stewardship and responsibility towards the environment, promoting sustainable development principles among the younger generation. This education translates into tangible changes in behaviour, as individuals with a thorough understanding of environmental interdependencies tend to adopt more sustainable lifestyle choices (Prasad and Alizadeh, 2020).

The role of different institutes in providing education that promote Pro-environmental behaviour in India can be depicted on table below.

Institutes	Contribution to Sustainable Forest Management	Alignment with SDG 4 Targets
Indian Institute of Forest Management (IIFM), Bhopal	IIFM offers postgraduate and doctoral programs in forest management, environmental management, conservation, and livelihood management. These programs aim to create professionals capable of managing forests sustainably and implementing pro-environmental policies. (Patel, Sharma, and Singh, 2020).	Contributes to 4.7 by promoting education for sustainable development and global citizenship.
Indian Gandhi National Forest Academy, Dehradun	This academy trains Indian Forest Service officers. Its curriculum is designed to incorporate forest management best practices, focusing on sustainable and conservation-centric approaches. (Tomaselli et al., 2019).	Contributes to 4.3, by ensuring equal access to affordable technical, vocational, and higher education, including forest management.
Forest Survey of India (FSI), Dehradun	FSI undertakes forest resource surveys, research, and training in resource management. The training programs offered by FSI aim to build capacity for sustainable forest management. (Prasad and Alizadeh, 2020).	Aligns with 4.4, by increasing the number of individuals with relevant skills, including technical and vocational skills, for sustainable development.
Wildlife Institute of India (WII), Dehradun	The WII offers training programs, academic courses, and advisory in wildlife research and management. By promoting wildlife conservation and management, it contributes to overall forest sustainability. (Nautiyal, Smitha, and Kaechele, 2020).	Contributes to 4.7 by fostering knowledge and skills needed to promote sustainable development and biodiversity conservation.

Table 5.2: The role of different institutes in providing education that promote Pro-environmental behavior in India.

SDG 5: Gender equality

Research findings indicate that women play a significant role in the extraction of forest resources within tribal families in India (Kanowski et al., 2019). Women's intimate knowledge of forest resources, honed by their role as gatherers, is an invaluable asset for forest management (Karanth and DeFries, 2010). Yet, their potential contribution to sustainable forestry is often overlooked, and they are less likely to receive relevant training (Tambe et al., 2020). This lack of capacity building among women inhibits India's efforts to achieve sustainable forest management. In the context of SDG 5: Gender Equality, this represents a significant challenge. It suggests a disparity in opportunities and an under utilization of resources, thereby hampering progress toward achieving gender equality (Thakur, 2020).

Addressing this issue would enhance the capacity of women in forest management and aid the country's progress towards SDG 5. By equipping women with knowledge and skills in sustainable forestry, we could help leverage their unique understanding of forest resources. This move could enhance resource management and foster gender equality in line with SDG 5 (Tewari, Kumar, and Gadow, 2020). For example, including women in decision-making processes and providing them with equal opportunities for training could improve resource utilization and encourage a more equitable distribution of resources.

SDG 6: Clean water and sanitation

Forests and water are interconnected components of the Earth's ecosystem, each sustaining and being sustained by the other (Verma et al., 2017). Forests play a pivotal role in maintaining the health of water systems by filtering pollutants, stabilising soils to prevent erosion, and influencing the quantity and timing of water flow (Katila et al., 2019; Srivastava and Barman, 2019). Preserving trees ensures that these vital ecosystem services remain intact, leading to the availability of clean water and sanitation.

The Namami Gange Program, an initiative by the Indian Government to clean and protect the Ganga River, underscores the importance of clean water sources for sustainable forestry (Kathiresan, 2018). As the Ganga River constitutes 26% of India's landmass, its health directly impacts the vast tracts of forest along its banks. This initiative has not only reduced pollution in the river but also positively impacted the forest ecosystems dependent on it. For example, the reduction in pollution levels has led to improved health of riparian forests along the Ganga, enhancing the biodiversity and resilience of these ecosystems (Williams et al., 2018).

The interdependence between forests and water creates a natural synergy between sustainable forestry and SDG 6, clean water, and sanitation. By preserving trees and implementing responsible forestry practices, ecosystems can better provide their vital services, including filtering pollutants, preventing soil erosion, and regulating water flow (Katila et al., 2019). The availability of clean water and proper sanitation is a critical target under SDG 6.1.

Sustainability in the forest and the protection of water resources are both targets of SDG 6 (Kathiresan, 2018), as shown by the Namami Gange programme in India. Water quality improvement (Target 6.3) is a direct result of this initiative. Target 6.6, which aims to preserve and restore ecosystems dependent on water, is therefore met via the enhancement of the Ganga's riparian woodlands (Williams et al., 2018; Ravindranath, Chaturvedi, and Murthy, 2008).

SDG 7: Affordable and clean energy

The correlation between sustainable forestry and SDG 7, Affordable and Clean Energy, has been extensively acknowledged. According to Katila et al. (2019), the implementation of sustainable forestry practices has the potential to make a direct contribution to the provision of clean energy. This can be achieved through the utilization of bioenergy sources. The "Pradhan Mantri Ujjwala Yojana" (PMUY) is a notable initiative introduced by the Government of India. The primary objective of this initiative is to offer complimentary Liquefied Petroleum Gas (LPG) connections to women belonging to households that fall below the poverty line. The overarching goal is to protect their well-being and address the adverse environmental consequences associated with the use of biomass for cooking purposes (Roy, 2020; Rout, 2018).

The Prime Minister Ujjwala Yojana (PMUY) demonstrates a positive correlation with sustainable forestry practices, thereby increasing the likelihood of attaining Sustainable Development Goal 7 (SDG 7). This is achieved by diminishing reliance on conventional biomass sources, such as forest wood, to meet energy requirements. This aligns with target 7.1, which aims to ensure universal access to affordable, reliable, and modern energy services (Gorain and Malakar, 2020).

SDG 8: Decent work and economic growth

The interconnections between sustainable forestry initiatives and SDG 8, Decent Work and Economic Growth, have been emphasized in numerous studies. As Devisscher et al. (2019) explain, sustainable forestry can spur economic growth and create decent employment opportunities by promoting the sustainable use of forest resources and innovating in forestry technologies.

The Government of India has embraced advanced technologies like remote sensing, GIS, IoT, block chain, and AI to augment the productivity of forests (Gorain and Malakar, 2020; Joshi, 2020). By enabling accurate and real-time tracking of forest health, growth, and resource extraction, these technologies can guide the sustainable management of forests (Bettinger et al., 2016). For example, remote sensing and GIS can map deforestation and degradation patterns, while

IoT and AI can provide early warnings for forest fires or pests (Khare, Vajpai, and Gupta, 2021). This information can inform conservation efforts, enhancing forest productivity and resilience.

SDG 9: Industry, innovation, and infrastructure

The interplay between sustainable forestry and SDG 9, which prioritises Industry, Innovation, and Infrastructure, is characterised by a diverse range of interconnected and strong dynamics. According to Biswas et al. (2017), the progress made in industry and technology has the potential to greatly improve the effectiveness and environmental friendliness of forest management. Additionally, the presence of a strong infrastructure can support the creation and delivery of forest derived products and services (Kishwan, Pandey, and Dadhwal, 2009). An example of a synergistic initiative can be observed in the Indian Government's efforts to foster the growth of innovative industries centered on forest resources.

The government's promotion of the bamboo industry serves to stimulate innovation in various aspects such as product development, processing techniques, and market strategies. This initiative aligns with target 9.5 of Sustainable Development Goal 9, which emphasizes the importance of advancing scientific research and enhancing technological capabilities within industrial sectors (Ramaiah and Avtar, 2019). In addition, the advancement of the bamboo industry requires enhancements in transportation and distribution infrastructure, thereby making a contribution to the achievement of target 9.1. This target aims to foster the development of infrastructure that is of high quality, dependable, sustainable, and resilient (Borah, Bhattacharjee, and Ishwar, 2018). In terms of sustainable forestry, the promotion of the bamboo industry encourages the cultivation of a renewable resource, which can mitigate pressure on other forest resources and help preserve forest health and biodiversity (Sreedharan and Matta, 2010).

SDG 10: Reduced inequalities

The interplay between diminished disparities and sustainable forestry in India is founded upon the intrinsic link between equitable social conditions and the preservation of the environment. According to the research conducted by Sayer et al. (2019), the promotion of equality can be achieved by implementing sustainable forest management practices that ensure fair distribution of and authority over forest resources. In India, there are two notable initiatives that contribute to the promotion of sustainable forestry practices and the mitigation of inequalities. These initiatives include the Forest Rights Act (FRA) of 2006 and the Joint Forest Management (JFM) program. The Forest Rights Act (FRA) acknowledges the entitlements of forest-dwelling communities, such as tribal populations, to forest lands and resources (Reddy et al., 2015). Additionally, the FRA serves to facilitate the achievement of Sustainable Development Goal 10, particularly target 10.2, which emphasizes the need to empower and promote social, economic, and political inclusion for individuals of all ages, genders, abilities, races, ethnicities, origins, religions, economic statuses, or other backgrounds (Rawat et al., 2008).

The Joint Forest Management (JFM) program, on the other hand, is another initiative that promotes both sustainable forestry and reduced inequalities. JFM involves the collaborative management of forests by the Forest Department and local communities, promoting sustainable forestry while sharing benefits equitably among participants (Ramaiah and Avtar, 2019). The aforementioned strategy effectively mitigates disparities by guaranteeing that the advantages derived from the implementation of sustainable forest management practices are distributed in a comprehensive and fair manner. This contributes to the attainment of target 10.1 outlined in Sustainable Development Goal 10, which seeks to progressively attain and sustain income growth for the bottom 40 per cent of the population at a rate surpassing the national average (Borah, Bhattacharjee, and Ishwar, 2018).

SDG 11: Sustainable cities and communities

The linkage between Sustainable Cities and Communities and sustainable forestry in India lies in the fact that well-managed urban forests can contribute significantly to making cities more livable, resilient, and sustainable while also providing ecosystem services and habitat for biodiversity. This connection is particularly relevant in the context of rapid urbanization and climate change (Cheng et al., 2017). One key initiative in India is the "Nagar Van (Urban Forest)" scheme, launched in 2020 on the occasion of World Environment Day. The scheme aims to develop 200 'Nagar Van' or city forests across the country over the next five years (Shah, 2020). In addition, this endeavor actively contributes to the achievement of Sustainable Development Goal 11.7, which specifically advocates for the establishment of widespread availability of secure, inclusive, environmentally friendly, and publicly accessible spaces.

An additional endeavor known as the National Clean Air Program (NCAP) acknowledges the significance of urban forests and green spaces in mitigating air pollution. According to Reddy et al. (2015), the National Clean Air Program (NCAP) incorporates the implementation of tree planting initiatives within urban regions as a means of mitigating air pollution and enhancing air quality. This initiative not only promotes the progress of sustainable forestry within urban areas but also makes a valuable contribution towards achieving Sustainable Development Goal 11.6, which aims to mitigate the environmental effects of cities, including improvements in air quality.

SDG 12: Responsible consumption and production

The synergy between responsible forest consumption and SDG 12: Responsible Consumption and Production is undeniable. Forest products provide a myriad of essential goods; however, they must be sustainably managed and utilized to prevent deforestation and degradation (Sayer et al., 2019). Thus, education about responsible forest consumption can have a profound impact on achieving SDG 12, fostering sustainable consumption patterns and ensuring sustainable management of natural resources (Cheng et al., 2017). Yet, initiatives from the Government of India regarding this specific issue are lacking. To fully leverage this synergy and drive progress towards sustainable forestry and SDG 12, more comprehensive and strategic actions promoting responsible consumption and production of forest products are urgently required (Shah, 2020; Schr€oder et al., 2019).

SDG 13: Climate action

The link between climate action and sustainable forestry constitutes a key synergy, as forests play a major part in the process of mitigating climate change by acting as carbon sinks and absorbing CO2 from the atmosphere (Sharma et al., 2020). Sustainable forestry is the practice of managing forests in a way that minimizes their negative impact on the environment while preserving their natural resources. On the other hand, practices that contribute to sustainable forestry assist in preserving these carbon stores and increasing their capacity, which contributes directly to climate action. The National Action Plan on Climate Change (NAPCC), which was developed by the Government of India, is one of the most important efforts in this regard. According to Sharma, Sood, and Chaudhry (2019), the NAPCC recognizes sustainable forestry as an essential approach for both the mitigation and adaptation of the effects of climate change. This strategy is in line with Sustainable Development Goal 13.2, which calls for incorporating actions to combat climate change into national policy.

Another program is called the Green India Mission, and its goal is to maintain, restore, and increase India's forest cover while also mitigating the effects of climate change and making communities more resilient, particularly those populations that are reliant on India's forests (Singh, Pandey, and Prakash, 2011; Sharma, 2001). This mission was introduced in 2010. By increasing resiliency and the ability to adapt to climate-related disasters, this effort helps bring about Sustainable Development Goal 13.1 (SDG 13.1).

SDG 14: Life below water

The nexus between life below water and sustainable forestry is vitally important as forests, particularly mangrove forests, play an essential role in preserving aquatic ecosystems and species (Biswas et al., 2017). Sustainable forestry practices can significantly contribute to achieving SDG 14 by protecting these essential ecosystems. One of the primary initiatives for this is the Mangrove Forest Conservation and Management Program by the government of India. Mangroves, being the interface between terrestrial and marine ecosystems, play a pivotal role in conserving aquatic biodiversity (Borah, Bhattacharjee, and Ishwar, 2018). This program seeks to restore and conserve mangrove ecosystems, contributing directly to SDG 14.2, aiming at sustainable management and protection of marine and coastal ecosystems.

Another initiative is the Integrated Coastal Zone Management (ICZM) project. The ICZM, by implementing sustainable forestry practices in coastal areas, protects marine environments, including coastal and marine areas, from harmful human activities (Ramaiah and Avtar, 2019). It directly contributes to SDG 14.1, which seeks to prevent and significantly reduce marine pollution of all kinds. Moreover, the National Mission for Clean Ganga, although primarily aimed at cleaning the Ganga River, has significantly contributed to life below water (Sreedharan and Matta, 2010). The afforestation activities along the Ganga River under this mission help reduce soil erosion and sediment load in the river, which has a direct impact on the river's biodiversity (Rawat et al., 2008). This initiative resonates with SDG 14.5 which focuses on conserving at least 10% of coastal and marine areas.

SDG 15: Life on land

The concept of sustainable forestry is inherently interconnected with the goals outlined in

Sustainable Development Goal 15, which focuses on the preservation and promotion of life on land. The objective of this goal is to safeguard, rehabilitate, and advance the sustainable utilization of terrestrial ecosystems, arrest and reverse the deterioration of land, and put a stop to the decline in biodiversity (Kanowski et al., 2019). This initiative has played a crucial role in safeguarding the biodiversity of forests, thereby making a direct contribution to the achievement of targets 15.1 and 15.5 outlined in Sustainable Development Goal 15. These targets specifically aim to ensure the preservation, restoration, and sustainable utilisation of terrestrial and inland freshwater ecosystems and their associated services.

An additional endeavour is the Green India Mission, which seeks to augment the forest/tree cover in order to enhance ecological services and elevate the forest-based livelihood income of approximately three million households (Tambe et al., 2020). This initiative makes a direct contribution to target 15.7 of Sustainable Development Goal 15 by establishing economic incentives that promote forest conservation and sustainable utilisation. The objective of target 15.7 is to put an end to the illegal activities of poaching and trafficking of protected species. Additionally, the National Afforestation Programme (NAP) seeks to restore deteriorated forests and adjacent lands by involving the local populace (Tewari, Kumar, & Gadow, 2020). This initiative is in accordance with target 15.2, which advocates for the promotion of sustainable forest management and the cessation of deforestation.

There are a good number of policies by the government of India that promote sustainable forest management. The table is presented below:

Policy	Objective and Contribution to SFM
National Forest Policy, 1988	***Objective***: Maintain environmental stability through preservation and restoration of ecological balance.
	Contribution: Introduced the concept of joint forest management involving local communities, contributed to SFM through enhancing cover, conserving biodiversity, meeting livelihood needs, and involving community participation.
National Environmental Policy, 2006	***Objective***: Conservation of critical environmental resources, intra-generational equity, livelihood security for the poor.
	Contribution: Provides a framework to regulate, augment, and monitor the country's forests, contributing to SFM by integrating environmental concerns into policies, plans, and programs for economic development.
Draft Wetland Policy, 2016	***Objective***: Conserve wetlands to prevent degradation and ensure their wise use for the benefit of local communities.
	Contribution: The policy recognizes the role of wetlands in maintaining ecological balance and providing livelihoods, contributing to SFM by protecting these crucial ecosystems that are linked to surrounding forests.
National Agroforestry Policy, 2014	***Objective***: Encourage and expand tree planting in complementarity with crops and livestock components on farmlands for integrated benefits.
	Contribution: Contributes to SFM by promoting diversified tree cover, enriching biodiversity, reducing deforestation, improving soil health, and ensuring sustainable livelihoods.

Table 5.3: Policies in India to promote sustainable forest management

There are different schemes under Indian forestry governance, which also results in achieving other targets of sustainable forestry. The table is presented below.

Indian Forestry Schemes	Objectives and Contribution towards Forestry	Relation to SDG 15 Targets
National Afforestation Programme (NAP)	***Objective***: To promote tree plantation, ecological restoration, and biodiversity conservation through people's participation.	15.1 and 15.2
	Contribution: Enhances Forest cover and promotes sustainable management of forests.	
Green India Mission (GIM)	***Objective***: To protect, restore, and enhance India's diminishing forest cover and respond to climate change.	15.1 and 15.2
	Contribution: GIM has not only increased the country's forest cover but also has been significant in promoting carbon sequestration.	
Intensification of Forest Management Scheme (IFMS)	***Objective***: To strengthen forest protection and management measures.	15.5, 15.6, 15.7, and 15.8
	Contribution: It has aided in mitigating forest fires, controlling pests and diseases, and strengthening research and training capacity in forest management.	
Integrated Development of Wildlife Habitat (IDWH)	***Objective***: To provide for the protection and development of wildlife and its habitats.	15.5 and 15.7
	Contribution: The program has been instrumental in conserving the country's biodiversity, especially in protected areas.	
Project Tiger	***Objective***: To ensure the survival and conservation of tigers in India.	15.5 and 15.7
	Contribution: This program has significantly contributed to the conservation of tigers and their habitat.	
Project Elephant	***Objective***: To protect elephants, their habitat, and corridors.	15.5 and 15.7
	Contribution: This initiative has been significant in safeguarding the habitats of elephants and mitigating human-elephant conflict.	
	Contribution: The program has facilitated the recovery of forest cover in areas where it was lost due to human activities.	

Table 5.4: Different Schemes Aiding Sustainable Forest Management

SDG 16: Peace, justice, and strong institutions

According to Forsell et al. (2016), the synergy between sustainable forestry and Sustainable Development Goal 16 (India): Peace, Justice, and Strong Institutions is centred on encouraging peaceful and inclusive communities, ensuring access to justice for all, and establishing effective, accountable institutions at all levels. The Forest Rights Act (FRA) of 2006 is one of the primary steps that has been taken to promote this synergy. According to Barik and Mishra (2008), the Forest Rights Act (FRA) is an attempt to make up for past wrongs committed against forestdwelling tribes by recognising their rights to forest land and resources. The act not only coincides with SDG 16 by strengthening marginalised people, notably in terms of land ownership and access to resources, but it also makes a contribution to sustainable forestry by fostering stewardship among those who depend most directly on forests (Baumgartner, 2019). This is how the act contributes to sustainable forestry. This programme makes a direct contribution to achieving objective 16.3, which encourages adherence to the rule of law and guarantees that everyone has equal access to justice.

The Compensatory Afforestation Fund Act (CAFA) of 2016 is another project that was passed in 2016. According to Bhattacharya, Pradhan, and Yadav (2010), the purpose of this piece of law is to both preserve and expand India's forest cover. It does so by making it a requirement that any economic activity that results in deforestation must be compensated by afforestation elsewhere. The act's primary objective is to encourage sustainable forestry; however, it also strengthens institutional accountability by requiring industries to take responsibility for their impact on the environment (Diduck, Patel, and Malik, 2021). This contributes to target 16.6 of SDG 16, which aims to develop institutions that are effective, accountable, and transparent.

SDG 17: Partnerships for the goals

The collaborative efforts and shared responsibilities among many stakeholders, including government institutions, non-governmental organisations, local communities, and foreign partners, are the foundation of the synergy that exists between sustainable forestry in India and SDG 17: Partnerships for the Goals. This synergy was identified as one of the 17 Sustainable Development Goals (SDGs) in 2015.

India has been an active participant in the REDD+ system, which is a partnership under the United Nations Framework Convention on Climate Change (UNFCCC). This activity has taken place on the world stage. According to Bhullar (2008), REDD+ offers poor nations financial incentives to cut emissions caused by deforestation and forest degradation, as well as to encourage the protection of forests, the practise of sustainable forest management, and the increase of forest carbon stores. According to Bettinger et al. (2016), it makes international relationships and financial support easier to get for forest preservation activities, therefore proving worldwide cooperation for sustainable forestry.

India's forestry plays a crucial role in achieving the SDGs, demonstrating a holistic approach to sustainability. From promoting clean water and sanitation (SDG 6) through watershed development (Verma et al., 2017) and afforestation (Williams et al., 2018), to providing affordable, clean energy (SDG 7) by transitioning to LPG (Roy, 2020), sustainable forestry contributes to various SDGs. It also fosters economic growth (SDG 8) with tech-led innovations (Khare, Vajpai, and Gupta, 2021), supports responsible consumption and production (SDG 12) through education and policy (Shah, 2020), and aids in climate action (SDG 13) with programs like REDD+ (Bhullar, 2008). Lastly, strong partnerships (SDG 17) amplify these efforts (Katila et al., 2019). The summary of the findings can be found in the table below.

5.5 The Inter-connectedness between Forest and Water and their Policy Integration: A Policy Network Analysis

This research delves into the criticality of cross-sectoral policy integration and natural resource management, especially in the context of India's ecological landscape (Scott, Kurian, & Wescoat, 2015; Löw, 2020). In an era marked by climatic changes and resource degradation, the integration of policies governing forest ecosystems and water management has emerged as a vital strategy for crafting responsive and resilient approaches to environmental stewardship and socio-economic development (Creed et al., 2016; Dewulf et al., 2005; Frost et al., 2006; Sotirov & Arts, 2018; Swain & Ranganathan, 2021). This integrated approach transcends traditional boundaries, aligning diverse policy domains to effectively respond to the multi-dimensional challenges presented by climate change and sustainable development.

The forest and water nexus in India presents a unique case study. The interconnection between these two resources is profound, transcending mere geographical or biological parameters (He et al., 2019; Kurian & Ardakanian, 2015). Forests, crucial in hydrological cycles, contribute significantly to watershed protection, groundwater recharge, and biodiversity while also being vulnerable to factors like deforestation, water scarcity, and climate change (Ghosh, Chatterjee, & Dinda, 2021; Löw, 2020). This calls for an interdisciplinary approach to policy-making that addresses the ecological, socio-economic, and policy dimensions of this intricate relationship.

Policy networks are central to this discourse, serving as a complex web of stakeholder interconnections with diverse objectives and interests (Gilissen et al., 2016). These networks function both as a nexus for different objectives and as a conduit for synthesizing these into cohesive policy outputs. The challenge lies in harmonizing these varying aims and operationalising actions to ensure coherence and efficiency. Systematic collaboration and consensus-building within these networks are crucial for aligning individual goals with collective priorities, thereby mitigating resource competition conflicts (McCollum et al., 2018).

However, the Indian context presents specific challenges. The limitation of resources and blurred lines of responsibility complicate the task of reconciling varied objectives (Löw, 2020; Poddar, Qureshi, & Shi, 2014). Despite the growing recognition of policy integration globally, there is a notable research gap in applying these concepts specifically within the Indian framework, especially from a policy network perspective (Scott, Kurian & Wescoat, 2015). Addressing this gap is essential not only to understand the intricate interconnections within the Indian policy landscape but also to contribute new insights to the literature. The study aims to provide a comprehensive understanding and a pragmatic approach to policy integration in India's evolving environmental context.

Hence, the study will address the below research questions.

RQ1: How the forest ecosystem and water are interconnected in the Indian context?

RQ2: How can policy networks impact forest and water policy integration in India?

RQ3: How policy network can be designed to maximise the positive policy integration outputs?

5.6 Theoretical and Analytical Framework

For India, the path towards effective cross-sectoral policy integration necessitates a comprehensive understanding of the ecological, socio-economic, and policy dimensions of the forest-water nexus. It requires the establishment of mechanisms for systematic collaboration and consensus-building among all stakeholders involved. Emphasizing the need for integrated, multi-disciplinary management strategies and policies, the approach must account for the complex interdependencies between forests and water, with a focus on sustainable management and cross-sectoral coordination (Escobedo et al., 2019; Mori, Lertzman, & Gustafsson, 2017).

5.6.1 The nexus between the forest ecosystem and water

The relationship between forest ecosystems and water is a complex interplay of ecological, climatic, and socio-economic factors, profoundly influencing both the environment and human life. Forests play a critical role in the global water cycle, regulating water quantity, quality, and timing and acting as natural filters, thus contributing significantly to hydrological functions

(Grossiord et al., 2014; Escobedo et al., 2019). Beyond their hydrological contributions, forests are vital for climate regulation through carbon sequestration and biodiversity conservation, and they also support livelihoods and cultural values (Singh et al., 2014; Sheil, 2018).

In India, this nexus is particularly intricate due to the country's diverse forest types, each offering various ecosystem services related to water, such as groundwater recharge and streamflow regulation (Port et al., 2016; Rasul, 2014). However, challenges like deforestation, climate change, and urbanisation threaten this delicate balance. Addressing these challenges requires integrated, multi-disciplinary management strategies and policies that account for the complex interdependencies between forests and water, emphasising sustainable management and crosssectoral coordination (Mori, Lertzman, & Gustafsson, 2017; Escobedo et al., 2019).

5.6.2 Cross-sectoral policy integration

Cross-sectoral policy integration, operating at the intersection of diverse policy sectors, entails balancing policy outputs with the reconciliation of varying interests within these sectors. This integration, characterised by its dual nature as both a process and an output, presents a dynamic and complex landscape in policymaking (Baulenas & Sotirov, 2020; Milhorance, Le Coq, & Sabourin, 2021). The success of policy integration hinges on understanding the end goals and the intricate processes involved (Wiedemann & Ingold, 2022; Bazzan et al., 2023). Aligning or reconciling differing sectoral objectives and approaches can either facilitate cohesive policymaking or lead to fragmentation.

The concept of policy networks is central to this discourse, offering a framework to analyse the causal effects and interactions among actors in policy integration. These networks, forming through ideational similarities, play a pivotal role in achieving effective cross-sectoral policy integration (Baulenas & Sotirov, 2020). However, the inherent complexities and potential discord among actor ideologies pose significant challenges to seamless integration. Research indicates that embracing these contradictions, rather than trying to eliminate them, offers a deeper understanding and a more nuanced approach to navigating the intricacies of policy networks and their influence on policy integration (Wiedemann & Ingold, 2022; Bazzan et al., 2023).

The Indian context, with its diverse ecological landscapes and pressing environmental issues such as deforestation, water scarcity, and climate change, underscores the urgency of cross-sectoral policy integration. However, achieving this integration is fraught with challenges. The complexity of navigating between the different policy sectors, each with its distinct objectives, mandates, and governance structures, can lead to policy fragmentation rather than cohesion (Baulenas & Sotirov, 2020; Milhorance, Le Coq, & Sabourin, 2021). This fragmentation is exacerbated by the inherent tensions and contradictions among the various stakeholders, including government entities, local communities, private sector actors, and environmental organizations, which often have divergent interests and priorities.

Moreover, the Indian policy landscape is marked by a multiplicity of regulatory frameworks and jurisdictional overlaps, further complicating efforts towards unified policy objectives (Löw, 2020). The blurring of responsibilities and limited resources available for environmental governance challenge the operationalisation of integrated policy approaches, making the task of reconciling varied objectives more daunting.

In addressing these challenges, the role of policy networks emerges as critical. Policy networks, characterized by the ideational similarities among actors, offer a platform for facilitating dialogue, building consensus, and aligning objectives across sectors (Baulenas & Sotirov, 2020). These networks can serve as a mechanism to bridge the gaps between different policy domains, fostering a more coordinated and holistic approach to managing the forest and water nexus.

However, the effectiveness of policy networks in promoting integration is contingent upon the capacity to navigate the ideological differences and competing interests within the network. The research by Wiedemann and Ingold (2022) and Bazzan et al. (2023) highlights the importance of acknowledging and managing these contradictions, rather than seeking to eliminate them. This approach can lead to a deeper understanding of the complexities involved in policy integration and facilitate the development of more nuanced and adaptive strategies.

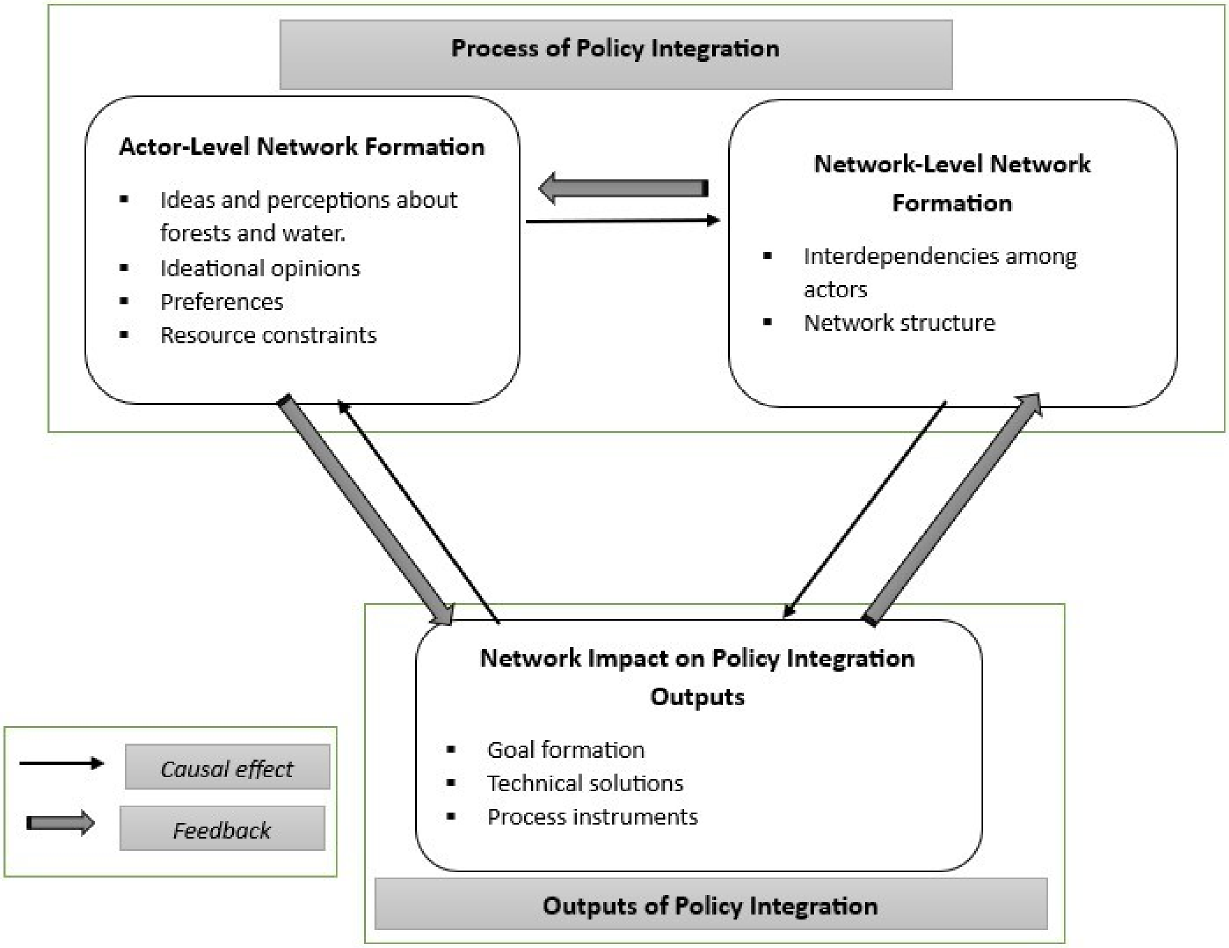

Figure 5.6: Cross-sectoral policy integration- The theoretical framework of the study

Source: Adapted from Wiedemann & Ingold, 2022; Bazzan et al., 2023

5.6.3 Process of policy integration – actor-level network formation

The process of policy integration at the actor-level within water and forest policy networks is a complex interplay of enforced collaboration and shared objectives. Legal mandates and policy changes act as significant drivers for actors within these networks to align their goals, as indicated by Baulenas, Kruse & Sotirov (2021) and Qvist (2017). This enforced alignment is often necessitated by the legal frameworks and evolving policy landscapes, as detailed by Locatelli et al. (2020) and Di Gregorio et al. (2019), where actors are compelled to cooperate, sometimes even amidst divergent interests.

A critical aspect of this process is the congruence in policy preferences among actors, which underpins the formation of an effective network. This congruence, extending beyond mere alignment of goals, forms the foundation for effective cross-sectoral integration (Wäsche, 2015; Mignon, 2016). It fosters a shared understanding that enhances collaboration and mitigates conflicts that may arise from legal or policy compulsions. However, ideational cleavages, representing deep-seated differences in values, beliefs, or ideologies, can disrupt this balance, leading to policy disintegration (Yi & Scholz, 2016; Velázquez Gomar, 2016).

The actors' ideas, perceptions, and opinions are integral to the network's formation. They shape their strategies and interactions within the network, influencing the overall direction of policy integration (Möck, 2021; Eräranta & Mladenović, 2021b). Furthermore, a mutual belief in the seriousness of policy issues acts as a 'glue' that binds actors together, fostering a collective commitment to integrated approaches in water and forest management. Yet, this 'glue' also depends on a reasonable level of mutual understanding among actors, without which the network can become fragmented and ineffective.

The process of policy integration at the actor level, specifically in the context of forest and water management in India, hinges on the delicate balance between enforced collaboration and the voluntary alignment of goals among various stakeholders. Baulenas, Kruse, and Sotirov (2021), along with Qvist (2017), underscore the importance of legal frameworks and policy changes in driving actors towards common objectives. This alignment, often necessitated by policy and legal mandates as discussed by Locatelli et al. (2020) and Di Gregorio et al. (2019), underscores the complexity of achieving consensus among actors with potentially divergent interests.

The effectiveness of this integration relies heavily on the congruence of policy preferences among the actors, a concept highlighted by Wäsche (2015) and Mignon (2016). Such congruence fosters a collaborative ethos, essential for mitigating conflicts arising from the enforcement of policies. However, ideational cleavages, as pointed out by Yi & Scholz (2016) and Velázquez Gomar (2016), can significantly disrupt this balance, leading to disintegration rather than cohesion in policy direction.

Moreover, the role of actors' perceptions and the mutual recognition of policy issues, as noted by Möck (2021) and Eräranta & Mladenović (2021b), cannot be overstated. This collective belief acts as a binding agent for the network, emphasizing the necessity of a shared understanding for effective policy integration. However, the absence of such mutual comprehension can lead to fragmentation, undermining the network's effectiveness in policy integration within India's forest and water sectors.

5.6.4 Process of policy integration – network-level network formation

In the realm of policy integration, particularly at the network level, the dialectic approach plays a crucial role in effectively assembling networks. This approach transcends the binary of idealism and materialism, acknowledging that both elements critically influence network potency (Agneessens, Trincado-Munoz & Koskinen, 2022; Segato & Raab, 2019). At the actor level, tangible factors like time, skills, and resources are pivotal, while at the network level, the utility of these factors is maximized through interdependencies among actors (Levalle & Nof, 2015; Yi & Yuan, 2023). These interdependencies, essential for resource exchange, reflect complex interactions between private and public sectors, where each sector seeks cooperation and resources from the other for policy-making and innovation.

This interplay of interdependencies forms a multifaceted balance crucial for network formation, as discussed by Andresen, Roxenhall & Frick (2015) and Kim et al. (2016). The convergence of shared ideas with material resources is key in overcoming collective action challenges (Parida & Wincent, 2019). Guo et al. (2022) identify four types of interdependencies - competitive, symbiotic, absent, and synergetic - each influencing policy integration differently. Synergetic interdependencies are ideal, where the alignment of ideas and resources fosters a collaborative environment conducive to successful policy integration. These interdependencies necessitate skilful navigation to ensure effective integration and highlight the importance of mutual reliance and negotiation in policy network formation.

At the network level, the integration of policies for forest and water management in India involves a nuanced interplay of ideas and practical resources, as highlighted by Agneessens, TrincadoMunoz, and Koskinen (2022), and Segato & Raab (2019). This integration transcends simple dichotomies, requiring a blend of ideological alignment and material cooperation. The importance of interdependencies among actors is emphasized by Levalle & Nof (2015) and Yi & Yuan (2023), indicating that the effectiveness of a network relies on the mutual exchange of resources and cooperation across sectors.

Andresen, Roxenhall, and Frick (2015), along with Kim et al. (2016), discuss the balance between shared objectives and the pooling of resources as critical for overcoming challenges in collective action. Guo et al. (2022) further categorize these interdependencies into competitive, symbiotic, absent, and synergetic, with synergetic interdependencies being the most conducive to policy integration. In the Indian context, fostering these synergetic relationships is key, requiring stakeholders to navigate complexities and ensure that both ideas and resources are aligned for the successful integration of forest and water policies.

5.6.5 The Role of policy networks on the outputs of policy integration

Policy integration outputs, essential in the context of forest and water management, are shaped by the network of interactions and commonalities among actors (Le Blanc, 2015). These outputs are influenced by ideational homogeneity within the network, where shared goals and ideas among actors lead to cohesive and aligned policy results (Adam & Kriesi, 2019; Li & Chen, 2015). Conversely, a diversity of ideas can result in disjointed efforts, reducing the effectiveness of policy outcomes (Di Gregorio et al., 2019). The nature of interactions within the network, whether collaborative or conflicting, also significantly impacts the quality of these policy outputs. Synergistic interactions typically yield stronger, more effective policy results, whereas discord among actors can impede policy goals (Locatelli et al., 2020).

Additionally, the density of relationships within the network is pivotal. Networks with weak ties offer flexibility and foster innovation but may risk policy cohesion due to potential fragmentation (Douglass, 2018). In contrast, networks characterized by dense ties provide stability and trust but may resist change, potentially hindering innovation and adaptability in policy outputs (Wallace et al., 2020). Balancing these dynamics—ideational congruence, interaction quality, and network density—is crucial for successful policy integration in forest and water management, underscoring the need for nuanced understanding and strategic management of these factors (Murphy & Gouldson, 2020; Qvist, 2017; Cheung & Phillimore, 2017).

5.7 Research methodology and methods

This study, exploring the interplay between forest ecosystems and water in India and their policy integration, adopts an ideational network perspective. This approach, essential in understanding the complexity of cross-sectoral policy-making, allows for a comprehensive exploration of stakeholder interconnections and idea flows within the water and forest policy context (Romberger and Mikola, 2013; Hui et al., 2019). A qualitative research method was used, employing SemiStructured Open-Ended Interviews to gather in-depth insights from selected public and third-sector officials. This method is justified by its ability to provide a nuanced understanding of policy network dynamics and integration processes (Wang et al., 2021; Magagnotti et al., 2013; Lu et al., 2016).

Madhya Pradesh was chosen as the study's focal region due to its rich forest and water resources, offering a suitable backdrop for analysing forest and water policy networks (Rasul, 2014; Escobedo et al., 2019). Purposeful sampling ensured participants had significant experience in water and forest management, providing a balanced view of both policy formulation and implementation (Tang and Shao, 2015; Doimo, Masiero, and Gatto, 2020).

Data analysis was conducted using MAXQDA, selected for its systematic coding and categorising capabilities, which are ideal for handling complex qualitative data sets and uncovering intricate patterns and themes relevant to policy networks and their influence on environmental management (Lowman, Schowalter and Franklin, 2019; Shi et al., 2020).

5.8 Results

The study's analysis of stakeholder interviews elucidates the intricate interconnection between forest ecosystems and water resources in India. Key stakeholders, including Divisional Forest Officers and Flood Management Officers, highlight forests' critical role in regulating water cycles, which is essential for groundwater recharge, soil stability, and river flow (Poddar, Qureshi, & Shi, 2014). This connection is vital for watershed health and flood mitigation. Local policies increasingly align forest conservation with water management, as seen in integrated watershed management and afforestation initiatives (He et al., 2019). However, challenges like urbanisation and land-use changes pose risks to this balance.

Opportunities lie in community-based management and scientific research for sustainable practices. Successful examples include community-led riverbank reforestation and watershed management, which have enhanced forest cover and water quality. Stakeholders also recognise climate change's significant impact, with strategies like drought-resistant tree planting and sustainable land management being crucial for ecosystem resilience. These insights, aligned with the literature (Scott, Kurian, & Wescoat, 2015; Löw, 2020), reflect the growing understanding of the interplay of forests, water resources, and climate change.

This research delves into the formation and impact of policy networks on forest and water policy integration in India, employing the MAXQDA Code Co-occurrence Model to analyze interview data from stakeholders in forest and water management (Figure 5.7). The model reveals a network with predominantly weak ties within each sector and a notable absence of strong cross-sectoral ties, indicating limited depth in internal sector collaboration and a lack of integrated approach between the forest and water sectors. Despite recognizing the need for multi-stakeholder collaboration, conflicts of interest and resource scarcity hinder actual integration efforts, as seen in the discord between economic pursuits and conservation goals. This situation, reflected in the model's lack of strong cross-sectoral ties, underscores the challenges in fostering sustainable forest and water management.

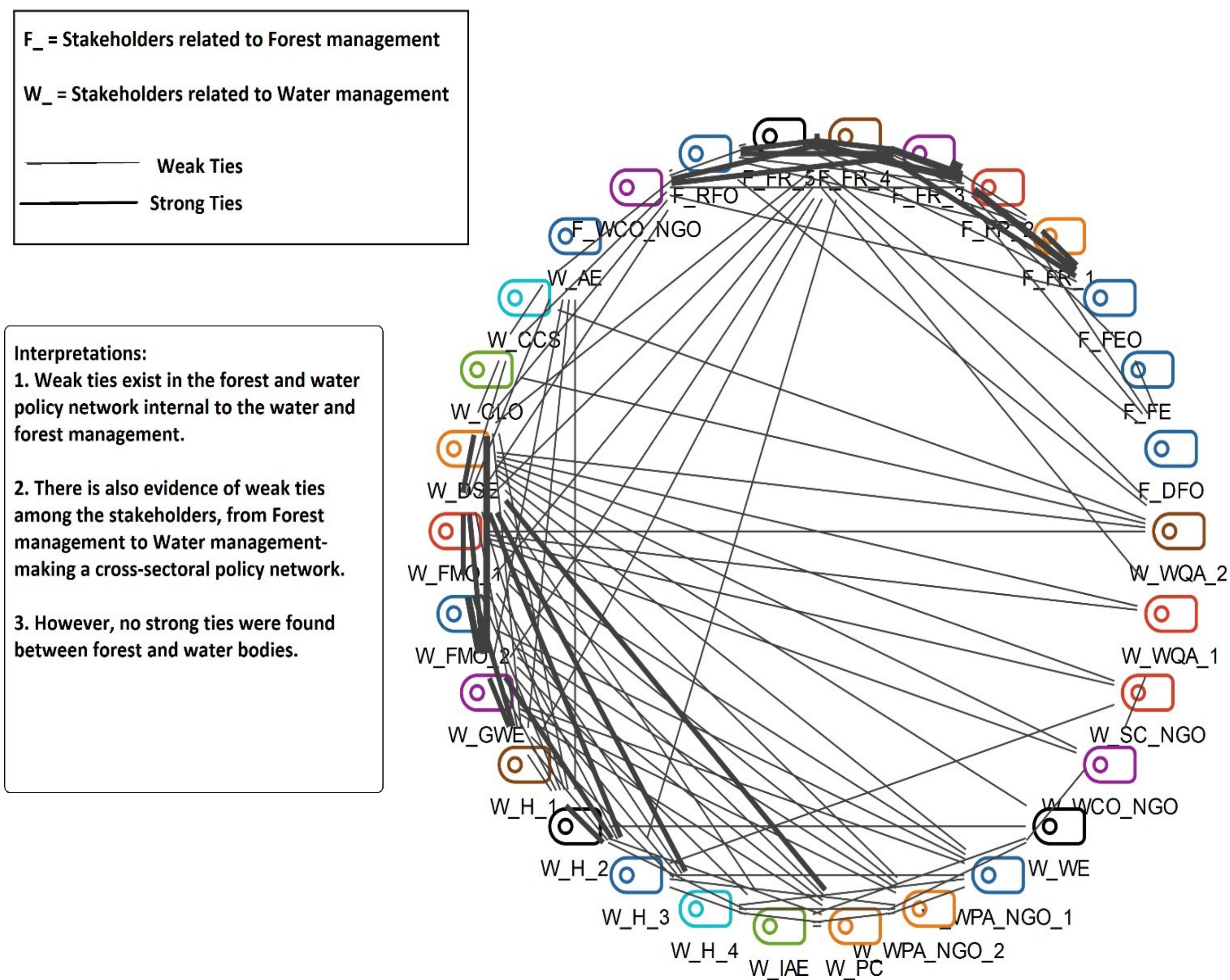

Figure 5.7: Policy Network Formation

Source: Author with MAXQDA Code Co-occurrence Model

The study also focuses on designing policy networks to maximize positive policy integration outputs. Key principles identified include sustainable resource use, community involvement, collaborative decision-making, and leveraging technology for predictive analysis and adaptive management. Inclusivity in decision-making and regular policy reviews are emphasized, ensuring policies remain relevant and effective. These recommendations, derived from stakeholders' insights, highlight the need for evolving management strategies and embracing innovative practices to respond to environmental challenges, thereby fostering sustainable development in forest and water management.

The findings from the research on the interconnectedness between forest ecosystems and water resources in India shed light on several critical aspects and challenges within the realm of policy integration for sustainable environmental management. Stakeholder interviews, particularly those with Divisional Forest Officers and Flood Management Officers, underscore the pivotal role of forests in water cycle regulation, highlighting their importance in groundwater recharge, soil stability, and river flow management (Poddar, Qureshi, & Shi, 2014). This relationship is fundamental to maintaining watershed health and mitigating flood risks, underscoring the necessity for policies that align forest conservation efforts with water management strategies.

The analysis points to both opportunities and hurdles in achieving effective policy integration. Community-based management and scientific research emerge as significant opportunities for promoting sustainable practices. Examples like community-led reforestation and watershed management initiatives demonstrate the potential benefits of enhancing forest cover and improving water quality through integrated approaches (He et al., 2019). However, urbanisation and land-use changes present formidable challenges, threatening the delicate balance between forest ecosystems and water resources.

A key finding from the MAXQDA Code Co-occurrence Model analysis is the prevalence of weak ties within sectors and the notable absence of strong cross-sectoral ties. This suggests limited collaboration within and between the forest and water sectors, highlighting a fragmented approach to policy integration. The lack of strong, collaborative ties is indicative of the challenges faced in reconciling economic pursuits with conservation goals, a recurring theme that underscores the difficulties in achieving sustainable management of forest and water resources.

The research further explores strategies for designing policy networks that can enhance positive policy integration outputs. Recommendations such as sustainable resource use, community involvement, collaborative decision-making, and the application of technology for management practices emphasize the importance of inclusivity and innovation in policy formulation and implementation. These principles are essential for adapting to environmental challenges and ensuring the relevance and effectiveness of policies over time.

5.9 Discussion

This study explores the intricate relationship between forest ecosystems and water resources in India and the impact of policy networks on forest and water policy integration. It also provides recommendations for designing effective policy networks to maximise positive integration outputs.

Research question 1 reveals the critical role of forests in regulating water cycles, soil stability, and watershed health, as highlighted by stakeholders like Forest Officers and Hydrologists. This aligns with secondary research emphasising forests' hydrological functions and the symbiotic nature of this nexus. Primary research adds depth with practical examples of successful integration strategies, such as community-led reforestation, which are less evident in secondary sources.

The study's examination of the interconnection between forest ecosystems and water resources in India (RQ1) showcases the essential roles forests play in hydrological cycles, soil stabilization, and overall watershed health. Stakeholders, including Forest Officers and Hydrologists, emphasized the importance of forests in water regulation, aligning with literature that highlights forests' hydrological functions (Poddar, Qureshi, & Shi, 2014; He et al., 2019). Practical examples, such as community-led reforestation, underscore the potential of integrated management practices. However, the findings also hint at challenges posed by urbanization and land-use changes, suggesting that while the connection between forests and water is well recognized, translating this understanding into widespread effective practice remains an area for improvement.

Regarding research question 2, the study uncovers weak ties within forest and water management sectors and a notable absence of strong cross-sectoral ties, using the MAXQDA Code Cooccurrence Model. This finding indicates fragmented integration efforts, contrasting with the literature that suggests effective integration is underpinned by ideational alignment and actor interactions. Primary research critiques the gap between theoretical policy network efficacy and its practical implementation, highlighting the need for stronger inter-sectoral collaboration.

The analysis of policy networks in India (RQ2) reveals a landscape characterized by weak intrasector ties and an absence of robust cross-sectoral connections, as illustrated through the MAXQDA Code Co-occurrence Model. This observation indicates a gap between the theoretical potential for effective integration, supported by literature on policy network effectiveness, and the reality of fragmented efforts in practice (Scott, Kurian, & Wescoat, 2015; Löw, 2020). The primary research points to conflicts of interest and resource scarcity as barriers to integration, emphasizing the disparity between economic development objectives and conservation needs. This suggests that while the necessity for integrated forest and water management is acknowledged, actual implementation struggles due to these inherent conflicts and a lack of comprehensive collaboration.

For policy network design (research question 3), the study suggests holistic and adaptive approaches. Key principles include sustainable resource use, community involvement, and technological integration for policy development. Policymakers are advised to focus on creating inclusive dialogue platforms, underlined by sustainability principles, to ensure policies are robust, equitable, and responsive to environmental changes.

Regarding the design of policy networks to maximize positive policy integration outputs (RQ3), the study advocates for approaches that are both holistic and adaptive. Recommendations for sustainable resource use, community involvement, and the application of technology in policy formulation are presented as essential for advancing policy integration. This strategic focus aims to bridge the gap identified between theoretical models and their practical application, suggesting that enhanced inclusivity, stakeholder engagement, and the employment of technological advances could foster more effective and sustainable management of forest and water resources in India. The emphasis on regular policy reviews and inclusivity in decision-making processes is particularly noteworthy, suggesting a path forward for policies to remain adaptable and relevant in the face of environmental and social changes.

In summary, the study underscores the importance of understanding the forest-water nexus and designing effective policy networks for integrated management. It suggests that while theoretical frameworks provide a basis, practical application in the Indian context reveals gaps that need bridging. Policymakers should focus on strengthening cross-sectoral ties, incorporating community insights, and leveraging technology to ensure effective, sustainable management of forest and water resources.

5.10 Conclusion

The study that was done across all of the Sustainable Development Goals (SDGs) demonstrates that there is a definite connection between environmentally responsible forestry practises and India's overall success in achieving all of the SDGs. The forest resource and associated industry in India contributes in a myriad of ways to the advancement of sustainable development. Not only does it play a part in the protection of the natural environment, but it also contributes in the areas of economics, society, and institutions. By providing natural resources and means of subsistence to underserved populations, sustainable forestry has a direct bearing on the achievement of SDG 1, which is the elimination of global poverty. It does this through preserving forest-based livelihoods, environmental services, and biodiversity, all of which contribute to the achievement of SDG 2: food security. It does this through providing clean air, medical supplies, and controlling disease vectors, all of which contribute to health and well-being (SDG 3).

To accomplish the goal of achieving gender equality (SDG 5), it is vital to implement forest management practises that include the active involvement of women. As natural water filters, forests contribute to the achievement of Sustainable Development Goal 6 (clean water and sanitation). In addition, the transition away from firewood and towards cleaner fuels as part of government-sponsored programmes helps to the achievement of the Sustainable Development Goal 7 (SDG 7). Productivity may be increased by the use of modern technology in forest management, which in turn promotes decent labour and economic expansion (SDG 8). In the framework of innovation and infrastructure (SDG 9), sustainable forestry contributes by using cutting-edge technology such as geographic information systems (GIS), internet of things (IoT), and artificial intelligence (AI). Through the engagement of local people in conservation efforts, forestry programmes also contribute to the achievement of Sustainable Development Goal 10, which aims to eliminate inequality.

The establishment of green space and urban forestry are both important parts of the endeavour to make cities and communities more sustainable (SDG 11). In the meanwhile, education on the responsible use of forests has an impact on the responsible consumption and production (SDG 12).

Carbon sequestration is another important way that sustainable forestry may help achieve Sustainable Development Goal 13 (to combat climate change). Sustainable forestry helps to the preservation of mangrove forests and other coastal ecosystems, which is a goal of Sustainable Development Goal 14 (SDG 14) mainly because protecting life on land is one of the Sustainable Development Goals (SDG 15), which is at the core of sustainable forestry. Sustainable forestry projects in India play a significant part in dispute resolution and the acknowledgement of forest rights, which are all important aspects of SDG 16, which focuses on promoting peace, justice, and strong institutions. Last but not least, the successful completion of these objectives cannot be accomplished without strong collaborations (SDG 17), which are also encouraged by the forestry industry. Therefore, sustainable forestry is not just about trees; it is closely intertwined with practically all areas of sustainable development, which makes it an important component in India's attempts to attain the Sustainable Development Goals (SDGs).

Summary of the chapter

The chapter investigates the synergy between sustainable development goals (SDGs) and Indian Forest Management," can be derived from its potential to transform institutional practices and improve natural resources governance. Understanding and exploring the SDGs' synergies with forestry can provide crucial insights to guide institutions towards better performance. These synergies are not simply about aligning forestry practices with SDGs but involve a more profound transformation of institutions to incorporate sustainability into their core functioning. For example, recognizing the links between forest conservation and climate action (SDG 13) can inform the development of more robust climate change strategies (Ahmad, 2011; Bhullar, 2008). Understanding the role of forests in poverty alleviation (SDG 1) and sustainable communities (SDG 11) can guide institutions to promote more inclusive and equitable forest management practices (Gill, 2016). In this sense, the study's findings can serve as a blueprint for institutions to reorient their operations towards a more sustainable and inclusive approach, thereby enhancing their performance (Das and Sanskar, 2021).

In the context of natural resource governance, particularly forest governance in India, these findings have profound implications. A nuanced understanding of how Indian forestry practices align with SDGs can provide a holistic view of forest governance, one that transcends the traditional conservation-focused perspective to encompass broader social, economic, and environmental considerations (Ahmad, 2011; Baumgartner, 2019). This can lead to more comprehensive and effective governance strategies. For instance, recognizing the interlinkages between forests, poverty, and inequality can shape policies that address these issues simultaneously, thereby promoting both forest conservation and social equity (Bhullar, 2008).

Moreover, the study can contribute to the development of governance mechanisms that ensure the sustainable use of forests (Das and Sanskar, 2021). The theoretical framework developed through the study can serve as a tool for tracking the impact of different governance practices on SDGs achievement, thereby enabling the refinement of these practices to enhance their effectiveness (Malik and Dhanda, 2003).

The chapter presents a theoretical framework called 'Adapted Sustainable Livelihoods Framework (ASLF)' that incorporates elements from the Sustainable Livelihoods Framework (SLF), Ecosystem Services Framework (ESF), and Natural Capital Theory. The seven elements of the ASLF are:

Livelihood Assets: The SLF encompasses various forms of capital, such as human, natural, financial, physical, and social capital, as discussed by Pandey et al. (2017). The significance of forests as a type of natural capital is underscored by the Sustainable Livelihoods Framework.

Ecosystem Services: Derived from the Ecological Services Framework (ESF), this component acknowledges the fundamental functions offered by forests, including the storage of carbon, water governance, conservation of soil, and biodiversity, which significantly contribute to human livelihoods and overall well-being (Pueyo-Ros, 2018).

Vulnerability Context: As in the SLF, this refers to external shocks, trends, and seasonality that can affect forest ecosystems and people's livelihoods (Pasanchay & Schott, 2021).

Forest Management Practices: This new element (drawn from Ecosystem Service Framework) focuses on how forests are managed, considering sustainable practices that maintain or enhance forest ecosystem services and contribute to the SDGs (Lele, 2013).

Institutional Structures and Processes: Adapted from the SLF's 'Transforming Structures and Processes', this element considers the role of forest-related policies, institutions, and governance in shaping livelihoods and forest management (Pandey et al., 2017).

Livelihood Strategies: This includes the diverse strategies people employ to make a living, influenced by their assets, the ecosystem services available, the vulnerability context, forest management practices, and institutional structures (Chen et al., 2013).

Sustainable Development Outcomes: This section, which builds on the 'Livelihood Outcomes' in the SLF, assesses the effect on larger sustainable development objectives, such as reducing poverty, ensuring food security, improving health and equality, taking action on climate change, and improving life on land (Kabonga 2020; Zenteno et al., 2013).

Analysing the interrelationships between forest management in India and the Sustainable Development Goals (SDGs) is made possible by the Adapted Sustainable Livelihoods Framework (ASLF), which is a powerful and thorough instrument. The various components of the ASLF, namely Livelihood Assets, Ecosystem Services, Vulnerability Context, Forest Management Practises, Institutional Structures and Processes, and Livelihood Strategies, are interconnected and interdependent, resulting in intricate interactions that shape the outcomes of Sustainable Development. The analysis conducted reveals that the Sustainable Development Goals (SDGs) have significant effects on every aspect of this framework, thereby necessitating a more sustainable, inclusive, and equitable approach to the management of forests. Nevertheless, this symbiotic relationship also faces various obstacles, including the clash between strategies for sustaining livelihoods and the preservation of forests, as well as disparities in the availability of forest resources. Addressing these challenges necessitates the implementation of comprehensive and tailored strategies that take into account economic, social, and environmental factors. These strategies should be consistent with the principles outlined in the Sustainable Development Goals (SDGs) and should be firmly rooted in the practicalities of local livelihoods and forest ecosystems. Hence, the Afforestation and Sustainable Forest Management Law (ASLF), in conjunction with the Sustainable Development Goals (SDGs), presents a significant framework for improving the management of forests in India, promoting the well-being of local communities, and progressing towards the achievement of wider sustainable development objectives. The present study's analysis and findings make a valuable contribution to the broader comprehension of the interconnections among forest management, sustainable livelihoods, and sustainable development.

Delving deeper into the rationale, the results of this study stand to substantially influence the functioning of institutions involved in forest management, and their interrelations with other entities. At the institutional level, understanding the synergies between the SDGs and Indian forestry can help in making informed decisions about decentralization, centralization, and coordination with NGOs and other authorities (Damania, Joshi, and Russ, 2020).

Decentralized forest management can greatly benefit from these findings. As it relies on local knowledge and community participation, understanding how forestry practices align with SDGs can support local decision-making, enhance community involvement, and promote sustainable practices at the grassroots level (Barik and Mishra, 2008). Moreover, NGOs, as crucial partners in sustainable development, can use these insights to refine their programs and initiatives to better support SDGs achievement through forestry projects (Andersson, 2018).

In the context of centralization, the study can inform higher-level decision-making and policy formulation. For example, understanding the multifaceted role of forests in achieving the SDGs can guide the allocation of resources, prioritization of initiatives, and formulation of policies at the national level, ensuring they align with sustainable development objectives (Katila et al., 2019). Furthermore, the results can improve coordination among different authorities. The findings can serve as a common ground for discussions and collaborations between formal and informal authorities, fostering a more coordinated and harmonious approach towards forest management (Khare, Vajpai, and Gupta, 2021).

From an international perspective, the study's insights into SDGs and forestry synergies are crucial. Organizations like the United Nations, IPBES, and the World Bank often use SDGs as a framework for their initiatives. Understanding these synergies can guide these organizations' strategies in countries like India, ensuring their programs are context-specific and aligned with the countries' unique sustainability challenges and opportunities. For example, the study can inform World Bank's funding decisions and UN's policy recommendations, making them more effective in promoting sustainable development through forest management (Kathiresan, 2018). Moreover, the study can contribute to the global discourse on sustainable development. By providing a detailed exploration of the synergies between SDGs and forestry in the Indian context, it can offer valuable insights for other countries facing similar challenges, enriching the global knowledge base and fostering international collaboration for sustainable development (Giribabu et al., 2019).

The chapter investigates the connection between forest ecosystems and water resources and their policy integration in Madhya Pradesh, India. It focuses on understanding this interplay and the role of policy networks in enhancing integration. Utilising qualitative methods, specifically SemiStructured Open-Ended Interviews and MAXQDA software for data analysis, the study gathers insights from public and third-sector officials (subject experts). Key findings highlight a complex network of relationships in forest and water management and provide recommendations for improving policy network design, stressing inclusivity and technology use. The research offers significant policy-making implications and suggests future areas of study in technological integration and balancing economic and environmental goals in natural resource management.

Chapter 6: Assessment of criteria and indicator system for sustainable forest management: A case study of Madhya Pradesh

6.1 Introduction

Forests are essential to the health of the planet because of the important roles they play in regulating temperature, protecting biodiversity, and keeping the planet's ecosystems in check. Sustainable forest management (SFM) is of utmost importance in India, a nation characterised by a variety of forest ecosystems and a significant portion of its populace reliant on forest resources. According to Bhojvaid et al. (2016), sustainable forest management takes into account a number of different goals, including the preservation of biodiversity, the capture of carbon, the upkeep of ecosystem services, and the provision of support for livelihoods. However, because of intricate socio-economic, cultural, and environmental elements, assessing and evaluating SFM offers a number of difficulties, especially in developing nations like India (Bhojvaid et al., 2016).

The forest resources of India are abundant and offer a wide range of goods and ecosystem services that hold significant economic, ecological, and societal value (Amarnath, Babar & Murthy, 2017). Nevertheless, a number of human and natural stressors are placing these forests in a more dangerous position (Rai et al., 2012). So, it's impossible to overestimate the significance of SFM in India. Krishnakumar and Yadav (2019) assert that it is imperative to not only guarantee the preservation and prudent utilisation of forest resources but also to foster the socio-economic advancement of the nation. To this end, it is crucial to put in place efficient C & I systems for tracking, assessing, and bettering SFM procedures.

The forests of India are integral to the country's environmental well-being, socio-economic development, and climate change mitigation efforts (Rajeev, 2011). However, these forests are increasingly threatened by numerous factors, including unsustainable practices, encroachments, climate change, and biodiversity loss (Kumar et al., 2021). The above-mentioned challenges underscore the pressing necessity for efficacious Sustainable Forest Management (SFM) tactics in India, thereby laying the groundwork for the current investigation.

The objective of Sustainable Forest Management (SFM) is to preserve and improve the economic, social, and environmental aspects of various forest types, with the intention of benefiting both current and future generations (Rajeev, 2011). The execution and surveillance of sustainable forest management (SFM) are intricate owing to the multifaceted characteristics of forest systems, which encompass ecological, socio-economic, and cultural dimensions (Kumar et al., 2021).

The statement highlights the necessity of conducting a thorough investigation that not only assesses the existing C & I framework but also devises enhanced techniques and approaches for Sustainable Forest Management (SFM) in India.

The criteria and indicator system represents a noteworthy advancement towards achieving the intended objective. The development of national-level criteria and indicators (C & I) for sustainable forest management (SFM) in India was first undertaken in 1999. This marked a significant and comprehensive effort, which included the identification of eight broad criteria and 47 associated indicators (Yadav & Dugaya, 2013). The process holds significance in our investigation as it establishes a fundamental basis for further development and enhancement.

6.2 Criteria and Indicators for Sustainable Forest Management: Evolution of the process

Singh et al. (2010) assert that the criteria and indicator system for SFM emerged as a result of an increasing recognition and dedication to sustainable forest management (SFM) in India, in conjunction with the requirement for a thorough and situation-specific mechanism to evaluate and supervise forest management methodologies. The origins of the criteria and indicator system can be traced to a pivotal occurrence that transpired in the early 2000s.

A seminar of international significance was held in Bhopal in 1999, with the aim of developing criteria and indicators for sustainable forest management in India. The seminar was attended by a variety of stakeholders, such as government officials, academic professionals, civil society groups, and communities that rely on forests. According to Aggarwal et al. (2015), this event was a pivotal moment in the way sustainable forest management (SFM) is approached in India. The BhopalIndia Process (now the C & I system) was established with the aim of implementing SFM as a practical and feasible approach, as described by Tiwari et al. (2019).

The formulation of the Bhopal-India Process was characterized by a systematic and participatory approach. It commenced with the establishment of thematic working groups responsible for developing and refining the Criteria & Indicator (C&I) system (Mohammadi & Limaei, 2018).

These working groups undertook a comprehensive review of existing international and regional C&I frameworks, analysing their relevance and applicability to the Indian context.

In tandem with the review process, extensive stakeholder consultations were conducted across the country, incorporating inputs from forest-dependent communities, foresters, policymakers, and scientists. This inclusive approach ensured that the C&I system reflected a wide range of perspectives and addressed diverse aspects of forest management (Saigal et al., 2013).

After a lengthy process, eight broad criteria and 47 related indicators were identified. These indicators covered a wide range of topics, including the preservation of biodiversity, the health and vitality of forests, the productive uses of forests, socioeconomic advantages, and the legal, policy, and institutional frameworks. The criteria and indicators presented by Datta and Chatterjee (2012) demonstrate a thorough and intricate perspective on sustainable forest management, which considers the intricate relationships among ecological, social, economic, and institutional elements. Following the development of the C&I system, a significant landmark in the C& I was the implementation of field testing for the C&I system. The study was conducted in diverse forest types throughout India, presenting a valuable prospect to evaluate the feasibility, pertinence, and efficacy of the C&I system in authentic scenarios (Chattopadhyay & Datta, 2010).

The C & I system has undergone a continuous evolution over time, which has been driven by shifting priorities, emerging challenges, and advancements in knowledge and comprehension of SFM. Jafari et al. (2018) have reported that contemporary advancements in the field of forestry encompass the integration of indicators pertaining to the consequences of climate change, the facilitation of ecosystem services, and the acknowledgement of the entitlements and well-being of communities that rely on forests. In general, the C & I system has made notable progress in promoting sustainable forest management (SFM) in India by employing a thorough and inclusive methodology. It demonstrates India's dedication to sustainable forest management and the balance of competing demands on the country's forest resources.

Several critical features set the C & I system apart as a distinct method of sustainable forest management (SFM) in India. The comprehensive and multifaceted approach to SFM that the C & I system takes is a key component (Kumar et al., 2021; Tewari, 2015). Nine broad criteria that cover diverse aspects of forest management were devised as part of the process, and they reflect this. Dwivedi et al. (2009) and Yadav and Dugaya (2013) list a number of reasons why forests matter, such as their role in biodiversity protection, their contribution to ecosystem health and vitality, the productive services they provide, the social and economic advantages they provide, and the legal and legislative frameworks within which they operate. The comprehensive strategy employed guarantees that the multifaceted and varied obstacles linked to sustainable forest management (SFM) in India are sufficiently tackled.

Another essential aspect of the C & I system for SFM is its focus on context-specific indicators. The 47 indicators associated with the eight criteria were developed based on an extensive review of international and regional C&I frameworks and in-depth stakeholder consultations (Rajeev, 2011; Kumar et al., 2020). This ensured that the indicators were relevant to the unique socioecological context of Indian forests and applicable to different forest types across the country (Iyengar & Bajaj, 2011).

The C &I also emphasizes the importance of a participatory approach towards SFM. From its inception, the process has sought to actively engage a broad array of stakeholders, including forestdependent communities, foresters, policymakers, and scientists (Singh et al., 2010; Aggarwal et al., 2015). This has not only ensured a more comprehensive and nuanced understanding of SFM but also enhanced the acceptability and applicability of the C&I system (Boafo, 2013). Moreover, the C & I system is characterized by its dynamic and adaptive nature. Recognizing the evolving challenges and priorities in forest management, the process has incorporated indicators related to emerging issues such as climate change impacts, provision of ecosystem services, and the rights and welfare of forest-dependent communities (Karmakar et al., 2020).

Thus, the C and I system is an all-encompassing, context-sensitive, interactive, and flexible method of SFM. The framework offers a systematic approach to evaluate and track the sustainability of forest management practises in India. Additionally, it offers direction for the formulation and execution of strategies and measures for sustainable forest management.

6.3 The key categories of the C&I system for SFM

The C&I system encompasses a broad spectrum of considerations for sustainable forest management (SFM), structured under three main categories: the ecological category, the economic category, and the socio-cultural category (Bharath et al., 2016). These categories recognize the multi-functionality of forests and ensure a comprehensive approach to SFM.

The ecological domain pertains to the preservation and augmentation of the ecological soundness of forested areas. The above statement comprises a set of standards and measures that pertain to the preservation of biological diversity, the robustness and vitality of forest ecosystems, and the safeguarding functions of forests, as stated by Dwivedi et al. (2009). The category in question acknowledges that the fundamental principles of sustainable forest management (SFM) are rooted in the ecological roles that forests play, including but not limited to providing habitats, sequestering carbon, conserving soil, and regulating water (Gupta et al., 2013). The practical implementation of ecological criteria and indicators is a multifaceted undertaking that is frequently hindered by conflicting land utilisation, inadequate data, and an incomplete comprehension of ecosystem dynamics. In order to effectively address these difficulties, forest management must adopt a strategy that is science-based, adaptable, and integrated (Iyengar & Bajaj, 2011; Boafo, 2013), and it must also include effective cooperation amongst a wide variety of stakeholders.

Functions of forests that contribute to economic growth and the use of forest resources fall under the economic heading. Karmakar et al. (2020) have outlined a set of criteria and indicators that pertain to the sustainable utilisation of forest resources, the economic valuation of forest services, and the role of forestry in fostering employment and generating income.

The financial viability of forest management poses a significant challenge despite the crucial role that forests play in supporting local and national economies, as noted by Datta et al. (2010). To attain economic sustainability, it is imperative to tackle concerns such as the depletion of forest resources due to excessive exploitation, the underestimation of the value of forest services, and the uneven allocation of forest benefits, as noted by Rasul et al. (2011).

The socio-cultural classification acknowledges the societal and cultural principles attributed to forests. Rishi and Khuntia (2012) have outlined a set of criteria and indicators that pertain to the socio-cultural advantages provided by forests, the rights and well-being of forest-dependent neighbourhoods, and the spiritual and cultural beliefs that are associated with forests. Although social and cultural factors are crucial, they are frequently disregarded in the context of forest management (Yadav, 2016). In order to ensure the social and cultural sustainability of forest management, it is imperative to address challenges such as the marginalisation of forest-dependent groups, conflicts over woodland assets, and the erosion of cultural and spiritual values, as noted by Rajendran et al. (2022).

In summary, the C & I comprises three distinct categories that offer a comprehensive framework for sustainable forest management. These categories encompass the ecological, economic, and socio-cultural dimensions of SFM. However, attaining sustainability across all dimensions is a challenging undertaking that requires context-specific methods, inclusive decision-making, and adaptive management (Sud et al., 2012).

6.4 Importance of the C & I system

Policy implications, practical application, and socio-ecological repercussions are just a few of the many reasons why the C & I system, a pioneering endeavour in the field of sustainable forest management (SFM) in India, is of such great importance (Chattopadhyay & Datta, 2010; Jafari et al., 2018). The C & I system has made noteworthy contributions to the development of forest management strategies and implementation in India at a policy level, as noted by Rasul et al. (2011). The establishment of a methodical and organised structure for evaluating the sustainability of forest management techniques has directed the advancement and improvement of forest policies, laws, and rules (Datta & Chatterjee, 2012). According to Datta et al. (2010), the utilisation of the process has facilitated the transformation of the SFM concept into feasible and implementable strategies, ultimately augmenting the efficiency of policy interventions.

According to Mohammadi and Limaei (2018) and Saigal et al. (2013), the C & I system has fostered a change towards evidence-based and adaptive forest management practises. This is one of the practical outcomes of the process. The Criteria and Indicator (C&I) system, which was formulated as a component of this process, functions as a crucial instrument for the surveillance and evaluation of forest management results. According to Rishi and Khuntia (2012), forest managers are able to monitor advancements, detect problematic regions, and implement appropriate modifications in forest management techniques through this process.

The Bhopal-India Process places significant emphasis on the principles of inclusivity and participation. The engagement of a diverse group of stakeholders in the creation and execution of the C&I system has resulted in the cultivation of a shared sense of responsibility and dedication towards sustainable forest management, as noted by Tewari (2015). The implementation of SFM practises has been improved in terms of acceptability and effectiveness, resulting in a more equitable distribution of forest benefits, as noted by Rajendran et al. (2022).

Addressing intricate and interrelated socio-ecological issues related to forest management has also been a major accomplishment of the C & I system. The process has been effective in enhancing comprehension of the interrelationships among the preservation of biodiversity, forest health, climate change, economic and social benefits, and institutional factors, owing to its thorough and multidimensional approach (Rajeev, 2011; Yadav & Dugaya, 2013). Yadav (2016) has indicated that the incorporation of SFM principles into wider land-use planning and decision-making procedures has been substantiated.

Finally, the C & I system has contributed to the capacity building of forest managers and stakeholders. Through its focus on training and awareness-raising, it has enhanced the understanding and appreciation of SFM principles and practices among diverse stakeholders, thereby strengthening their capacity to contribute to SFM efforts (Sud et al., 2012). Overall, the C & I system has significantly shaped the trajectory of SFM in India, influencing both policy and practice. By providing a comprehensive, context-specific, and participatory framework for SFM, it has contributed to enhancing the sustainability, effectiveness, and equity of forest management practices in India (Bharath et al., 2016).

6.5 The limitations of the C & I system

The C & I system, while offering a comprehensive framework for Sustainable Forest Management (SFM), encounters several limitations that pose significant obstacles to its effective application (Yadav & Dugaya, 2013). This section critically evaluates these limitations across various perspectives, including stakeholder engagement, implementation, data availability, and evolving challenges. One of the most cited limitations is the insufficient engagement of all relevant stakeholders (Kumar et al., 2021). Despite the participatory design of the process, certain stakeholders, particularly local communities and indigenous groups, often remain marginalized. This exclusion leads to issues in understanding and addressing local needs and priorities, thereby constraining the process's effectiveness in promoting truly sustainable and equitable forest management (Tewari, 2015).

Implementation hurdles represent another significant limitation. The C & I system although conceptually robust, has been confronted with several practical implementation challenges. These range from capacity constraints and resource limitations to institutional bottlenecks and policy misalignments. The absence of an effective and coherent implementation strategy has often resulted in the sub-optimal application of the C & I framework (Rajeev, 2011; Kumar et al., 2020). Data availability and reliability pose further constraints. The operationalization of the C&I system requires robust data on various dimensions of SFM. However, reliable and timely data is often unavailable, particularly at the local level. This absence of data compromises the assessment and monitoring of SFM and limits the utility of the Bhopal-India Process (Singh et al., 2010).

Lastly, the C & I system ability to respond to evolving challenges remains questionable. Forest ecosystems are increasingly confronted with emerging threats such as climate change, invasive species, and shifting socio-economic dynamics (Tiwari et al., 2019; Aggarwal et al., 2015). The C & I system, although designed to be dynamic, often struggles to promptly and effectively incorporate these emerging issues into its framework, compromising its relevance and effectiveness (Mohammadi & Limaei, 2018).

Addressing these limitations necessitates concerted efforts from various stakeholders, including government, academia, local communities, and non-governmental organizations (Datta & Chatterjee, 2012). Enhancing stakeholder engagement, improving implementation mechanisms, strengthening data systems, and enhancing the C & I system's adaptability are crucial steps towards unleashing its full potential for SFM in India (Saigal et al., 2013).

6.6 Criteria and Indicator (C&I) System for Sustainable Forest Management in India

Criteria 1: Increase in the Extent of Forest and Tree Cover

The first criterion, "Increase in the extent of forest and tree cover", is central to the sustainable management of forests in India, aiming to expand forested areas and improve the quality of existing forests. This criterion recognizes that an increase in the extent and health of forests can significantly contribute to biodiversity conservation, carbon sequestration, water regulation, soil conservation, and livelihood support (GoI, 2000; GoI, 2004). The summary of the criteria and its indicator systems can be found in table 1.

Criteria	Indicators	Contribution
Increase in the Extent of Forest and Tree Cover	1.1 Area and Type of Forest Cover under Natural Forest and Man-made Forest (Tree Plantations)	Provides information on the size and variety of forested areas, thus informing about biodiversity and potential ecosystem services.
	1.2 Forest Area Officially Diverted for Non-forestry Purposes	Offers insights into pressure on forests from competing land uses, helping to understand the balance between forestry and other socio-economic demands.
	1.3 Forest Area under Encroachment	Highlights illegal activities threatening forest resources, essential for law enforcement and protection strategies.
	1.4 Area of Dense, Open and Scrub Forests	Gives insights into forest quality, species diversity, and potential for ecosystem services, informing conservation and restoration strategies.
	1.5 Trees Outside the Forest Area	Illuminates the extent of biodiversity, carbon sequestration, and socio-economic benefits outside formal forest areas, highlighting the importance of integrated land use planning.

Table 6.2: The summary of the criteria and its indicator systems for criteria 1

Criteria 2: Maintenance, conservation and enhancement of biodiversity

The second criteria, "Maintenance, conservation and enhancement of biodiversity," relates to preserving and enhancing the rich biodiversity inherent in forest ecosystems. This includes all forms of life within the ecosystem, such as different animal and plant species, as well as the ecosystems themselves. Protection and enhancement of biodiversity is a key aspect of sustainable forest management as it underpins ecosystem health and resilience, supports livelihoods, and ensures the sustainability of forest resources for future generations. The summary of this criteria and its indicators system can be found in the table below.

Criteria	Indicators	Contribution
Maintenance, Conservation and Enhancement of Biodiversity	2.1 Area of protected ecosystems (protected areas)	Provides information about dedicated efforts to conserve biodiversity and natural features.
	2.2 Number of (a) animal and (b) plant species	Offers an assessment of the diversity and richness of the species present, a sign of a healthy and resilient ecosystem.
	2.3 Number and status of threatened species (a) animal (b) plant species	Offers insights into the conservation status of species, indicative of potential threats to biodiversity.
	2.4 Status of locally significant species (a) animal and (b) plant species	Indicates the health of locally significant species, supporting local livelihoods and cultural values.
	2.5 Status of species prone to over-exploitation	Reflects the vulnerability of certain species due to their economic value, helping prevent over-exploitation.
	2.6 Status of non-destructive harvest of wood and non-wood forest produce	Reflects the sustainability of harvesting practices, promoting the health of forest ecosystems and supporting local livelihoods.

Table 6.3: The criteria and indicator system for criteria 2.

Each of these indicators plays a critical role in understanding the current status and trends of forest biodiversity. They provide valuable information for decision-makers to establish effective conservation and management strategies and promote sustainable forest management practices that contribute to India's overall environmental, economic, and social goals (ITTO, 2005; IIFM, 2005b).

Criteria 3: Maintenance and enhancement of ecosystem function and vitality

The criterion "Maintenance and enhancement of ecosystem function and vitality" essentially aims to uphold the overall health of the forest ecosystem, not just by preserving its components, but also by encouraging practices that boost the functionality and vigor of the forest ecosystem (Yadav & Dugaya, 2013; Lattimore et al., 2013).

Criteria	Indicators	Contribution
Maintenance and enhancement of ecosystem function and vitality	3.1 Status of natural regeneration	Assesses the forest's ability to naturally rejuvenate, which is vital for its resilience and health.
	3.2 Incidences of forest fires	Monitoring forest fires provides essential data for creating strategies for prevention and recovery.
	3.3 Extent of livestock grazing - (a) Forest area open for grazing - (b) Number of livestock grazing in forest	Identifies areas of potential overgrazing and its impact, leading to strategies to mitigate the adverse effects.
	3.4 Occurrence of weeds in forest - (a) Area - (b) Weed type	Helps in the identification of invasive species and areas affected, contributing to effective weed management strategies.
	3.5 Incidences of pests and diseases	Early detection and management of outbreaks prevent extensive damage, preserving forest health.

Table 6.4: The criteria and indicator system for criteria 3

Criteria 4: Conservation and maintenance of soil and water resources

The evaluation of the criterion "Conservation and maintenance of soil and water resources" pertains to the implementation of measures aimed at safeguarding and regulating soil and water resources in the forest ecosystem. These resources are crucial for sustaining the general health, productivity, and ecological operations of the forest (Rodriguez Franco & Conje, 2022; Jafari et al., 2018). In conclusion, the combined use of these indicators contributes to the forest ecosystem's ability to monitor and manage the essential soil and water resources. They are essential to the longterm viability of forest functions, provide a contribution to climate control, encourage biodiversity, and guarantee the delivery of ecosystem services to populations both nearby and farther afield. Monitoring these indicators may help forest managers in India make more informed choices and put focused actions into place, both of which are important steps towards achieving more sustainable forest management.

Criteria	Indicators	Contribution
Conservation and Maintenance of Soil and Water Resources	4.1 Area under Watershed Treatment	It assists in maintaining water balance, controlling erosion, and enhancing biodiversity, critical for sustainable forest management.
	4.2 Area Prone to Soil Erosion	By identifying areas susceptible to soil erosion, it enables the implementation of targeted soil conservation measures, vital for maintaining soil health and forest productivity.
	4.3 Area Under Ravine, Saline, Alkaline Soils and Deserts (Hot and Cold)	Tracking these areas aids in the planning of specific management strategies for restoring or maintaining ecological functions in degraded lands.
	4.4 Soil Fertility/Site Quality	This indicator provides critical insights into soil nutrient status and productivity potential, underpinning forest health, growth, and carbon sequestration efforts.
	4.5 (a) Duration of Water Flow in Selected Streams (b) Groundwater in the Vicinity of the Forest Areas	These indicators assess the hydrological health of the forest ecosystem, supporting the conservation of both surface and groundwater resources crucial for forest health, wildlife habitats, and human communities.

Table 6.5: The criteria and indicator system for criteria 4

Criteria 5: Maintenance and enhancement of forest resource productivity

The criterion "Maintenance and Enhancement of Forest Resource Productivity" recognises the significance of productive forests, not only in terms of their ecological well-being but also in the continued supply of economically and socially essential goods and services. This has been highlighted in previous studies (Datta et al., 2010; Fabusoro et al., 2014).

Criteria	Indicators	Importance
Maintenance and enhancement of forest resource productivity	5.1 Growing stock of wood	Measures the overall productivity of the forest and potential supply of timber and non-timber forest products, ensuring a continued yield for future generations.
	5.2 Increment in volume of identified species of wood	Essential measure of the forest's productive capacity and reflects the success of sustainable management practices aimed at maintaining or enhancing specific tree species.
	5.3 (a) Technological inputs	Reflects the application of advanced techniques in forestry to enhance forest productivity.
	5.3 (b) Area under Hi-tech plantations	Reflects the extent of modernized forestry operations aimed at increasing productivity and sustainability.
	5.3 (c) Area under seed production areas, clonal seed orchards, etc.	Indicates proactive management measures that enhance the productive capacity of forests, thereby supporting sustainable forest management goals.

Table 6.6: The criteria and indicator system for criteria 5

Criteria 6: Optimization of forest resource utilization

The criteria "Optimization of forest resource utilization" is focused on ensuring that forest resources are used in the most efficient, sustainable, and beneficial way (IIFM, 2005b). This involves reducing waste, promoting equitable access and benefits, balancing supply and demand, and taking into account global forest product markets. Details of the criteria and its indicators can be found in table 6.

Criteria	Indicators	Contribution to Sustainable Forest Management
Optimization of Forest Resource Utilization	6.1 Recorded removal of wood	Monitoring the quantity of wood harvested can maintain sustainable harvest levels and protect forest health.
	6.2 Recorded collection of non-wood forest produce	The collection of non-wood forest products is crucial for assessing the forest's multifunctional use and promotes biodiversity conservation.
	6.3 Efforts towards reduction of wastages	Reduction of waste in forestry increases the efficiency of resource use, contributing to sustainability goals.
	6.4 Aggregate and per capita consumption of wood and non-wood forest produce	Assessing the demand for forest products helps in formulating sustainable management practices and understanding the potential strain on forests.
	6.5 Direct employment in forestry and forest-based industries	Jobs in forestry and related industries support local economies and provide stable, long-term employment through sustainable forestry practices.
	6.6 Contribution of forests to the income of forest dependent people	Forests provide income to many communities. Sustainable forest management can enhance livelihoods while preserving the forest's ecological integrity.
	6.7 Demand and supply of wood and non-wood forest produce	The balance between demand and supply is essential for sustainable forest management, preventing overharvesting and forest degradation.
	6.8 Import and export of wood and non-wood forest produce	Monitoring of trade in forest products can inform policies to promote sustainable trade and prevent deforestation due to overexploitation.

Table 6.7: The criteria and indicator system for criteria 6

Criteria 7: Maintenance and enhancement of social, cultural and spiritual benefits The criteria "Maintenance and enhancement of social, cultural and spiritual benefits" focus on preserving and fostering the societal, cultural, and spiritual values that forests offer. This includes community involvement in forest management, application of traditional knowledge, provision of concessions, and safeguarding of culturally or spiritually significant landscapes (Linser et al., 2018).

Criteria	Indicators	Importance
Maintenance and Enhancement of Social, Cultural and Spiritual Benefits	7.1 (a) Number of JFM committees and area(s) protected by them	Measures the extent of community-led forest management efforts, critical for sustainable local practices
	7.1 (b) Degree of people's participation in management and benefit-sharing	Indicates the inclusivity of forest management processes, crucial for sustainability and equity
	7.1 (c) Level of participation of women	Represents gender equity in forest management, vital for inclusivity and broad-based sustainability
	7.2 Use of indigenous technical knowledge: identification, documentation, and application	Assesses the integration of traditional knowledge in forest management, contributing to biodiversity conservation and adaptation
	7.3 Quality and extent to which concessions and privileges are provided	Reflects incentives for community involvement in conservation, key for promoting sustainable practices
	7.4 (a) Type and area of cultural/sacred protected landscapes: forests, trees, ponds, streams, etc.	Gauges the protection of culturally significant landscapes, preserving socio-cultural values and promoting ecotourism
	7.4 (b) Number of visitors	Evaluates public interest and engagement with protected landscapes, indicative of socio-cultural and potentially economic value

Table 6.8: The criteria and indicator system for criteria 7

Together, these indicators provide a comprehensive measure of the social, cultural, and spiritual benefits offered by forests. Enhancing these aspects can not only preserve traditional forest-related values and knowledge but also promote community participation and benefit-sharing, which are key for sustainable forest management (Jalilova et al., 2012).

Criteria 8: Adequacy of policy, legal and institutional framework

The criteria of "Adequacy of policy, legal and institutional framework" primarily assesses the effectiveness and capacity of the institutional structures, legal policies, and regulations that are set in place to manage and safeguard forests (Linser et al., 2018). This criteria is paramount for sustainable forest management as it directly reflects how committed and equipped a nation or region is in managing their forests sustainably (GoI, 2004; IIFM, 1999).

Criteria	Indicators	Contribution in Summary
Adequacy of policy, legal and institutional framework	8.1 Existence of policy and legal framework	Establishes the foundation for forest management, protection, and sustainable use.
	8.2 Number of forest-related offences	Provides insight into the level of adherence to and enforcement of forest laws and regulations.
	8.3 Level of investment in research and development	Aids in the development and implementation of improved, innovative, and sustainable forest management strategies.
	8.4 Human resource capacity building efforts	Crucial for equipping forestry staff with the knowledge and skills necessary for effective forest management.
	8.5 Forest resource accounting	Demonstrates the economic value of forests and the government's financial commitment to sustainable forest management.
	8.6 Monitoring and evaluation mechanisms	Essential for policy adjustment and improvement based on real-world feedback and data.
	8.7 Status of information dissemination and utilization	Promotes awareness, transparency, and participatory decision-making in forestry management.

Table 6.9: The criteria and indicator system for criteria 8

Each of these indicators plays a pivotal role in augmenting sustainable forest management practises in India. A comprehensive policy and legal framework serves as the foundation for effective forest management, with ongoing monitoring, evaluation, and dissemination of information being critical to the successful implementation and refinement of these policies. The improvement of forestry practises can be attributed to capacity building and investment in research and development. Additionally, forest resource accounting plays a crucial role in acknowledging the economic value of forests and providing sufficient financial support. The amalgamation of these components results in a conducive atmosphere for the implementation of sustainable forest management practises, as stated by IIFM (2005a) and Linser et al. (2018).

The summary of all the categories, criteria, and indicators are presented in table 6.9.

Category	Criteria	Indicators
Ecological	Increase in the Extent of Forest and Tree Cover	1.1 Area and Type of Forest Cover under Natural Forest and Man-made Forest (Tree Plantations)
		1.2 Forest Area Officially Diverted for Non-forestry Purposes
		1.3 Forest Area under Encroachment
		1.4 Area of Dense, Open and Scrub Forests
		1.5 Trees Outside the Forest Area
	Maintenance, Conservation and Enhancement of Biodiversity	2.1 Area of protected ecosystems (protected areas)
		2.2 Number of (a) animal and (b) plant species
		2.3 Number and status of threatened species (a) animal (b) plant species
		2.4 Status of locally significant species (a) animal and (b) plant species
		2.5 Status of species prone to over-exploitation
		2.6 Status of non-destructive harvest of wood and non-wood forest produce
	Maintenance and enhancement of ecosystem function and vitality	3.1 Status of natural regeneration
		3.2 Incidences of forest fires
		3.3 Extent of livestock grazing - (a) Forest area open for grazing - (b) Number of livestock grazing in forest
		3.4 Occurrence of weeds in forest - (a) Area - (b) Weed type
		3.5 Incidences of pests and diseases
	Conservation and Maintenance of Soil and Water Resources	4.1 Area under Watershed Treatment
		4.2 Area Prone to Soil Erosion
		4.3 Area Under Ravine, Saline, Alkaline Soils and Deserts (Hot and Cold)
		4.4 Soil Fertility/Site Quality
		4.5 (a) Duration of Water Flow in Selected Streams (b) Groundwater in the Vicinity of the Forest Areas

Category	Criteria	Indicators
Economic	Maintenance and enhancement of forest resource productivity	5.1 Growing stock of wood
		5.2 Increment in volume of identified species of wood
		5.3 (a) Technological inputs
		5.3 (b) Area under Hi-tech plantations
		5.3 (c) Area under seed production areas, clonal seed orchards, etc.
	Optimization of Forest Resource Utilization	6.1 Recorded removal of wood
		6.2 Recorded collection of non-wood forest produce
		6.3 Efforts towards reduction of wastages
		6.4 Aggregate and per capita consumption of wood and non-wood forest produce
		6.5 Direct employment in forestry and forest-based industries
		6.6 Contribution of forests to the income of forest dependent people
		6.7 Demand and supply of wood and non-wood forest produce
		6.8 Import and export of wood and non-wood forest produce
Socio-cultural	Maintenance and Enhancement of Social, Cultural and Spiritual Benefits	7.1 (a) Number of JFM committees and area(s) protected by them
		7.1 (b) Degree of people's participation in management and benefit-sharing
		7.1 (c) Level of participation of women
		7.2 Use of indigenous technical knowledge: identification, documentation, and application
		7.3 Quality and extent to which concessions and privileges are provided
		7.4 (a) Type and area of cultural/sacred protected landscapes: forests, trees, ponds, streams, etc.
		7.4 (b) Number of visitors
	Adequacy of policy, legal and institutional framework	8.1 Existence of policy and legal framework
		8.2 Number of forest-related offences
		8.3 Level of investment in research and development
		8.4 Human resource capacity building efforts
		8.5 Forest resource accounting
		8.6 Monitoring and evaluation mechanisms
		8.7 Status of information dissemination and utilization

Table 6.10: Summary of all categories, criteria and indicators

6.7 Comparing the relative importance of ecological, social, and economic categories of C&I systems for SFM India

According to Klein et al. (2007), the Ecological category places an emphasis on the robustness, variety, and overall wellness of forest ecosystems. According to Prabhu et al. (2001), this category defines and monitors the indicators that are necessary for the preservation of biodiversity, ecosystem services, as well as soil and water resources. According to Dale and Beyeler (2001), it offers a direct measurement of the ecological health of the forest and its potential to supply essential ecosystem services such as the management of water, the capture of carbon, and the provision of habitat. However, evaluating ecological indicators often calls for a great deal of hands on fieldwork and specialized scientific knowledge, which may be both time-consuming and expensive (Karp et al., 2013). Some indicators may not be easily quantifiable, and there can be lags between changes in management practices and observable effects on ecological indicators (Klein et al., 2007). Despite the challenges, the Ecological category is indispensable to SFM in India. It provides the biological baseline upon which forest management decisions should be based and a means of monitoring the ecological impacts of these decisions (Dale & Beyeler, 2001).

The Social category underscores the roles of forests in human societies (Dale & Beyeler, 2001). This category recognizes that sustainable management depends not only on ecological conditions but also on the support and participation of local communities and other stakeholders (ITTO, 1992). It emphasizes issues such as participatory management, indigenous knowledge, and the socio-cultural benefits of forests. Social indicators can be difficult to measure quantitatively, and they may vary significantly between different cultural, social, and geographical contexts (Gough et al., 2008). In India, where many rural communities rely heavily on forests for their livelihoods, the Social category helps to ensure that forest management strategies are socially equitable and supportive of these communities' needs and rights (Du Pisani, 2006).

The significance of economic sustainability in the context of forest management that ensures long-term ecological balance is emphasized in the Economic category, as stated by Wijewardana (2008). This category emphasizes the financial advantages that come from forests, including direct advantages like employment in the forestry industry and indirect advantages like the production of wood and non-timber forest products (FAO, 2011). Quantifying the economic contribution of forests has the potential to facilitate investment and policy support for sustainable practices. The exclusive reliance on economic metrics may fail to account for the significance of non-market forest resources, including cultural values, biodiversity, and carbon storage (Linser et al., 2018). This phenomenon has the potential to result in the undervaluation of the actual worth of forests. However, the Economic category is vital in supporting investments in sustainable management techniques and guiding policy decisions. According to Rametsteiner and Simula (2003), the financial viability of SFM in India is a fundamental aspect that is critical to ensuring the long-term sustainability of forest resources.

To sum up, the C&I systems' ecological, social, and economic categories give a comprehensive framework for SFM in India, each with its own advantages and disadvantages. The collective aspects of SFM are emphasized by them, highlighting the intricate relationship between the ecological, social, and economic aspects of forest management.

6.8 Interdependence and Trade-offs between Ecological, Social, and Economic Categories

The ecological, social and economic categories make up the Criteria and Indicators for Sustainable Forest Management. This dependency, on the other hand, might lead to trade-offs in situations where actions that benefit one group have unfavorable effects on another area.

Ecological and Social Interdependence

The well-being and vitality of forest ecosystems (which fall under the ecological category) play a crucial part in the maintenance of local populations' means of subsistence as well as their cultural practices (which fall under the social category). According to Siry et al. (2005), local populations are dependent on non-timber forest products such as food, fuel, medicinal plants, and other nontimber forest products. According to Reed et al. (2017), several indigenous people have strong cultural and spiritual links to the forest, which play an important role in both their sense of self and their overall well-being. In exchange, local people often contribute to the administration and preservation of the forest; one example of this is the implementation of Joint Forest Management practices in India (ITTO, 1992). However, there can be trade-offs. Extensive use of forest resources for livelihood needs can potentially degrade forest ecosystems. Conversely, strict conservation measures can restrict access to forest resources, impacting people's livelihoods and traditional practices (Dale & Beyeler, 2001).

Social and Economic Interdependence

Forests offer significant economic benefits, providing employment and income to individuals and communities (Economic category) through forestry and related industries. Local communities (Social category), in turn, provide the labor force for these industries and are often key stakeholders in forest management (van Kooten et al., 2005). Nonetheless, trade-offs can occur. For instance, large-scale commercial forestry can provide economic benefits but might displace local communities or change their traditional ways of life. Conversely, prioritizing local livelihoods can limit commercial exploitation, potentially affecting the economic viability of forest management (Wijewardana, 2008).

Economic and Ecological Interdependence

The viability of economic pursuits, such as the logging industry and the collection of non-timber forest products, is contingent upon the well-being and efficiency of forest ecosystems, as classified within the ecological realm. On the other hand, it has been reported that the income generated from said activities can be utilized to finance conservation endeavors, falling under the economic classification, as per sources such as the Food and Agriculture Organization (FAO) in 2011 and Karp et al. in 2013. Trade-offs are frequently observed in this context. The excessive utilization of natural resources for financial benefit has the potential to deteriorate ecological systems, thereby compromising their sustained productivity. Conversely, the implementation of rigorous conservation strategies may curtail prompt economic advantages, as posited by Gough et al. (2008).

To encapsulate, the interrelatedness among the ecological, social, and economic domains accentuates the significance of comprehensive and unified strategies for forest management, as posited by Linser et al. (2018) and Prabhu et al. (2001). The identification and effective handling of the trade-offs among these classifications pose a significant hurdle in attaining genuinely sustainable forest management.

6.9 C&I Systems for SFM in Other Countries

In order to direct their efforts, several nations have created their own Criteria and Indicator (C&I) systems. Sustainable forest management is a worldwide topic. Different forest kinds, socioeconomic situations, and governmental goals all have a role in how each country's C&I system is structured. Nonetheless, we may learn about both the shared and differentiated features of these systems via comparison.

The Montreal Process, a worldwide initiative comprising 12 nations that collectively possess 90% of the world's temperate and boreal forests, facilitated the establishment of the C&I system for sustainable forest management in the United States (McDonald & Lane, 2004; Rametsteiner & Simula, 2003). According to Linser et al. (2018), the United States system comprises of seven criteria and 64 indicators, with a significant focus on the surveillance of forest health and productivity, safeguarding biodiversity, and upholding soil and water resources. Indicators for the socioeconomic advantages of forests are also included in the U.S. system, which is noteworthy and shows that the U.S. government is aware of their many uses (Wijewardana, 2008).

With regards to Europe, it is noteworthy that the Pan-European Forest Process has devised a comprehensive set of criteria and indicators (C&I) to facilitate sustainable forest management. This system has gained significant traction and is currently implemented across the continent, as evidenced by the works of Wolfslehner et al. (2005) and Mrosek et al. (2006). According to Baycheva-Merger and Wolfslehner (2016) and Pokorny & Adams (2003), this approach, which consists of six criteria and 35 indicators, places a particular emphasis on preserving the biodiversity and health of forest ecosystems. Furthermore, the European system places emphasis on the economic and social roles of forests, encompassing the forestry industry's contribution to domestic economies and the significance of recreational amenities furnished by forests.

In contrast, Brazil possesses the world's largest tropical rainforest and has implemented a C&I system that is specifically designed to address the intricate and diverse challenges associated with managing such ecosystems (Linser et al., 2018). The Brazilian system prioritizes the preservation of biodiversity, the sustenance of forest ecosystem services, and the advancement of sustainable utilization of forest resources. The Brazilian system is noteworthy for its emphasis on the protection of the rights and well-being of indigenous and local communities, which is reflective of the country's social and cultural milieu (Pokorny et al., 2004; Stupak et al., 2011).

Finally, with regard to Southeast Asia, Indonesia and Malaysia have established C&I systems within the ITTO framework that are specifically designed for the management of forests that produce tropical timber (Pokorny et al., 2004; Stupak et al., 2011). The aforementioned systems prioritize the sustainable generation of timber, preservation of biodiversity, and delivery of socioeconomic advantages. McDonald and Lane (2004) and Rametsteiner and Simula (2003) acknowledge the significance of policy, legal, and institutional frameworks in facilitating efficient forest management.

To summarize, it can be observed that various nations possess distinct C&I frameworks pertaining to sustainable forest management. However, these systems exhibit certain similarities, such as acknowledging the multifaceted functions of forests, emphasizing the preservation of biodiversity and ecosystem well-being, and recognizing the significance of socio-economic advantages. The aforementioned shared priorities are indicative of the worldwide agreement regarding the fundamental elements of sustainable forest management.

6.10 Fuzzy Logic

Fuzzy logic is a mathematical approach that allows for degrees of uncertainty in reasoning, thereby emulating human-like thinking. It is particularly useful in complex situations with imprecise or incomplete data (Abedi Gheshlaghi et al., 2020). Unlike binary or classical logic, which asserts that things are either true or false, fuzzy logic allows for intermediate values, accepting that things can be partially true and partially false at the same time (Nebot & Mugica, 2021). In the context of sustainable forest management, fuzzy logic has significant potential. Traditional decision making models in this field often struggle to deal with the inherent complexities and uncertainties, particularly when trying to balance different and often conflicting objectives (Biber et al., 2021). For instance, a decision-maker might need to consider ecological, economic, and social factors simultaneously, each measured by different indicators and each affected by different degrees of uncertainty (de Souza et al., 2019).

By allowing for degrees of truth and accommodating imprecise information, fuzzy logic can help in such complex scenarios. It can handle the ambiguity inherent in real-world decision-making, making it particularly relevant for sustainable forest management (Bolourchi & Uysal, 2013).

Fuzzy logic can be applied to criteria and indicator systems in several ways. For instance, it can help in the prioritization of indicators, by allowing decision-makers to express their preferences in flexible and intuitive ways, rather than being forced to make precise numerical judgments (Pourghasemi et al., 2016). It can also be used in the interpretation of indicators, by providing tools to combine different indicators into overall assessments or to explore trade-offs between different objectives (Massoud et al., 2019). Furthermore, fuzzy logic can help incorporate stakeholder views into decision-making. By allowing for imprecise judgments, it can accommodate the diverse perspectives and preferences that stakeholders often have (Juvanhol et al., 2021).

Notwithstanding its merits, the utilization of fuzzy logic in the context of sustainable forest management is not without its difficulties. The proper establishment and interpretation of models necessitate a significant level of expertise. Khanna and Cheema (2013) have noted that communicating the outcomes of fuzzy analyses can pose challenges, owing to the unfamiliarity of many individuals with the associated concepts and techniques. Furthermore, akin to any modelling methodology, fuzzy logic does not obviate the necessity for astute discernment and contextual comprehension (Ghosh & Dey, 2021).

In summary, although fuzzy logic is not a universal solution, it provides potent instruments for addressing the intricacies and ambiguities of sustainable forest management. According to ToledoCastro et al. (2018), there is a possibility that it can improve the effectiveness of criteria and indicator systems, leading to better decision-making in the respective domain.

6.11 Analytical Hierarchy Process (AHP)

The Analytical Hierarchy Process (AHP) is a mathematical and psychological-based tool for multicriteria decision-making that facilitates the organization of intricate decisions. The Analytic Hierarchy Process (AHP), which was formulated by Thomas Saaty during the 1970s, offers a systematic approach for addressing decisions that entail multiple variables (Mohammadi Samani et al., 2010). The fundamental tenet of AHP is that the process of human decision-making frequently encompasses both quantitative and qualitative elements. According to Pokhriyal et al. (2020), the Analytic Hierarchy Process (AHP) enables decision-makers to create a sophisticated hierarchical structure of elements that represents a problem. Additionally, it facilitates the systematic assessment of numerous qualitative and quantitative factors.

The Analytic Hierarchy Process (AHP) holds significant relevance in the realm of sustainable forest management. Forest management decisions frequently require consideration of a broad spectrum of ecological, social, and economic factors (Unver & Ergenc, 2021). The Analytic Hierarchy Process (AHP) can be utilised to facilitate decision-making processes by deconstructing intricate problems into a set of uncomplicated pairwise comparisons. These comparisons can subsequently be employed to calculate relative priority scales, as suggested by Piran et al. (2013). According to Sivrikaya and Küçük (2022), the integration of multiple criteria and indicators into a unified decision-making process facilitates the adoption of a more comprehensive and equitable approach to management, thereby enabling more well-rounded and informed decisions.

Moreover, the structured approach of the Analytic Hierarchy Process (AHP) can aid in enabling stakeholder involvement in the process of decision-making. According to Pourghasemi et al. (2016), the incorporation of stakeholder preferences regarding various factors can facilitate the integration of diverse perspectives into the process of decision-making. Nevertheless, it is noteworthy that the Analytic Hierarchy Process (AHP) is not exempt from encountering certain obstacles. A crucial aspect of effective decision-making is the establishment of a precise and comprehensive definition of the decision problem and its constituent elements. Furthermore, as asserted by Pleșca et al. (2019), the proficiency of the decision-maker or decision-making team is a determining factor in the caliber of outcomes.

Despite this, the AHP is a potent instrument for the sustainable management of forests due to its capabilities in dealing with complicated situations involving several criteria. Lepetu (2012) and Ljubomir et al. (2019) both note that their capacity to manage both quantitative and qualitative data contributes to more sustainable solutions.

6.12 Methodology and analysis

This paper has made the best of the C&I, which has been developed on the above. The formation of the research data took place in two stages. In the first stage, the author of the study conducted surveys with individuals who have acquired significant knowledge on the subject issue. These experts have come from forest engineers, academics, and other stakeholders. With the means of surveys, the participants were asked to reduce the number of C&I applied in this study. It was necessary to ensure that the number of C&I should be reduced, ensuring that the equations remain simple (Abedi Gheshlaghi et al., 2020). In stage 2, based on the agreed C&I, a hierarchy was created, as depicted in Figure 1.

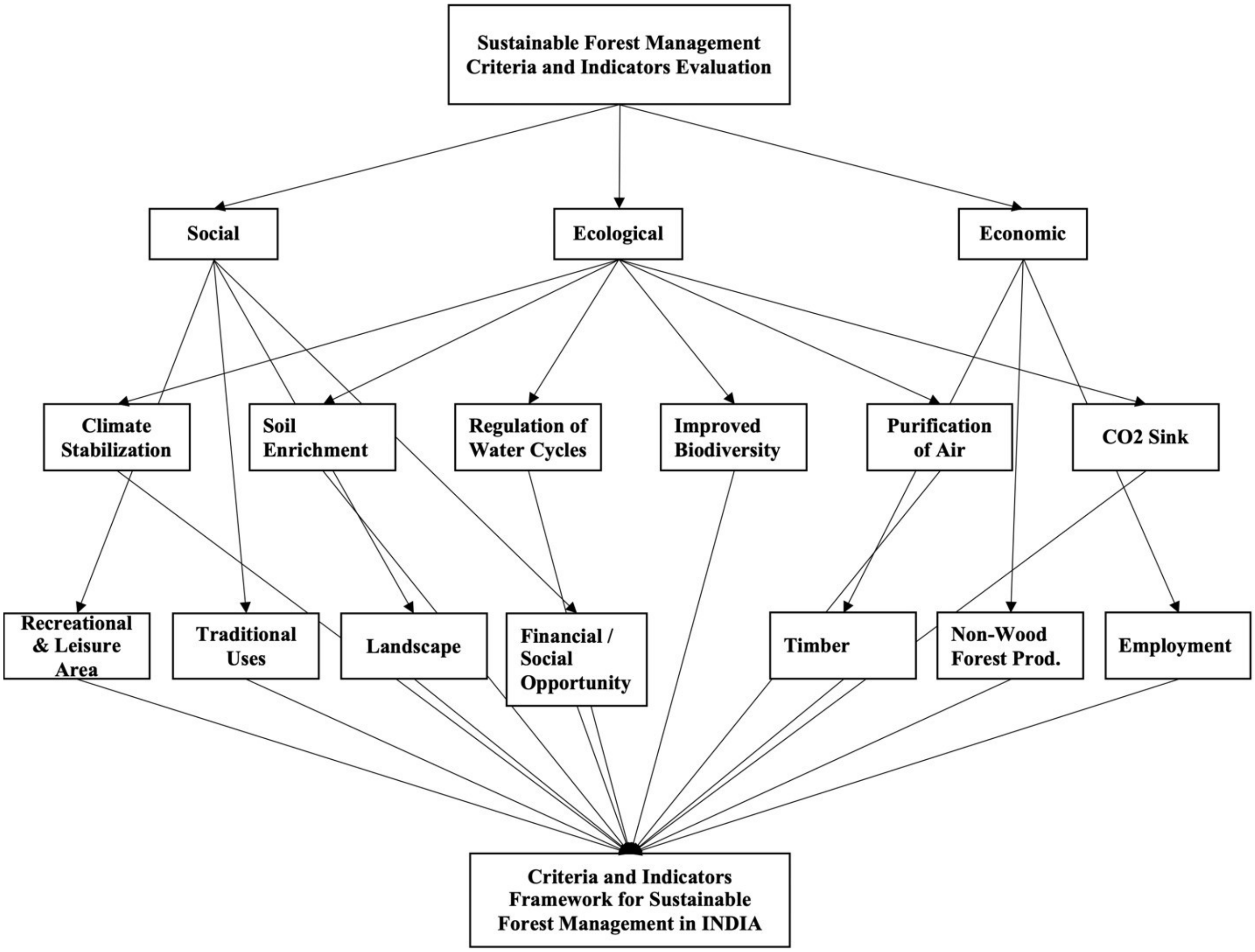

Figure 6.6: Sustainable Forest Management C&I hierarchy

In order to critically assess the hierarchy presented in Figure 6.1, the method that was used was the fuzzy AHP method. The justification for choice will be explained in a detailed manner in the Fuzzy analytic hierarchy process section. The author has developed a questionnaire to assess the effectiveness of the fuzzy AHP. The study's author conducted the survey with each of the ten specialists in turn. Comparing the relative relevance of one indication in comparison to another was the method that each of the experts used to carry out the survey. The fuzzy scale developed by Chang et al. (1996) was selected for use in the current investigation for conducting pair-wise comparisons (Table 6.10). Nonetheless, several fuzzy scales are accessible in the research that has been published; nonetheless, there is still no agreement on a scale that is generally recognized (Abedi Gheshlaghi et al., 2020).

Language Parameters	Triangular Fuzzy Scale	Triangular
Of Similar Significance	(1, 1, 1)	(1, 1, 1)
Relatively Significance	(2/3, 1, 3/2)	(2/3, 1, 3/2)
Significant	(3/2, 2, 5/2)	(2/5, 1/2, 2/3)
Highly Significant	(5/2, 3, 7/2)	(2/7, 1/3, 2/5)
Much more Significant	(7/2, 4, 9/2)	(2/9, 1/4, 2/7)

Table 6.11: The fuzzy scale of Chang et al. (1996)

Table 6.11 below shows the demographic data of the participants. The demographic data presented in Table 6.11 illustrates the characteristics of the participants involved in the study, categorized by their degree, age group, and gender. The total number of participants is 10, comprising 8 males and 2 females. In terms of educational qualifications, 1 participant holds a Bachelor's degree and falls within the 19-29 age group, 3 participants with Bachelor's degrees are in the 30-45 age group, 4 participants with Master's degrees are also in the 30-45 age group, and 2 participants, both females, hold Ph.D. degrees and are within the 30-45 age group.

This distribution of participants by degree suggests a higher representation of individuals with advanced degrees, which is relevant for the study as it implies a significant level of expertise and knowledge in the subject matter. The predominance of participants in the 30-45 age group indicates a mature and likely experienced cohort, further suggesting that the insights and feedback obtained would be informed by a combination of academic knowledge and practical experience.

The gender distribution shows a higher number of male participants than female, which is a demographic detail that could influence the perspectives and insights gathered, considering the potential for gender-related differences in views or experiences related to the study's subject matter.

DEGREE	AGE	GENDER		Total
		Male	Female	
Bachelor’s degree	19-29	1		1
	30-45	3		3

Master's Degree	30-45	4		4
Ph.D.	30-45		2	2
TOTAL		8	2	10

Table 6.12: Demographic data of the participants

Table 6.12 provides an overview of the professional backgrounds of the participants, detailing their professional affiliations, positions, and years of experience. The total participant count is 10, with their experiences distributed across various durations and roles related to forest management and environmental planning.

Specifically, 5 participants are affiliated with the Forest Department, serving as Forest Officers. Among these, 3 have 1-3 years of experience, 1 has 4-6 years, and 1 has more than 6 years of experience. This indicates a range of relatively fresh to seasoned perspectives within the forest management sector. Another participant works as an Inspector for the Agricultural Marketing Board, boasting more than 6 years of experience, suggesting a deep understanding of agricultural market dynamics and their intersection with forest resources. Lastly, 4 participants are Subject Experts in Climate Change with the Environmental Planning and Coordination Organization, with 2 having less than a year of experience.

BUSINESS	POSITION	EXPERIENCE				Total
		<1 Year	1-3 Years	4-6 Years	>6 Years	
Forest Department	Forest Officer		3	1	1	5
Agricultural Marketing Board	Inspector				1	1
Environmental Planning and Coordination Organization	Subject Expert (Climate Change)	2			2	4
TOTAL						10

Table 6.13: Professional data of the participants

The diversity in professional backgrounds and experience levels of these participants underscores their relevance to the study. Their varied insights can contribute to a comprehensive understanding of sustainable forest management, encompassing practical forest management, market dynamics, and climate considerations. Their expertise is crucial for evaluating and refining criteria and indicators for sustainable forest management, ensuring the study's findings are grounded in practical, diverse professional perspectives.

After that, we averaged everyone's opinions to get the fuzzy group decision matrix. The next part provided an explanation of the fuzzy AHP approach, as well as the steps to produce the fuzzy group decision matrix and the associated computations. A thorough understanding of fuzzy sets and fuzzy numbers is necessary before delving into fuzzy AHP. So, what follows is an explanation of the fundamental concepts.

Fuzzy sets and fuzzy numbers

The conceptual foundation of fuzzy set theory was introduced by Lotfi Zadeh in 1965, aiming to create a mathematical framework adept at handling the inherent vagueness and subjectivity encapsulated within human cognition (Zadeh, Klir, & Yuan, 1996). The term "fuzzy" pertains to the indistinct, nebulous boundaries characteristic of certain concepts or phenomena, which defy precise categorization within traditional binary frameworks of true or false (Chang et al., 1996; Abedi Gheshlaghi et al., 2020). Fuzzy set theory posits a continuum of truth values, ranging between 0 and 1, allowing for the representation of intermediate states of membership which are neither fully in nor fully out of a particular set (Nebot & Mugica, 2021).

The import of fuzzy set theory in decision-making, particularly under conditions of uncertainty, is immense. When decision-makers are confronted with incomplete or imprecise data, fuzzy sets offer a sophisticated tool to perform decision analysis by incorporating elements of ambiguity and nuance (Bolourchi & Uysal, 2013; de Souza et al., 2019). Unlike traditional set theories that mandate categorical judgments, fuzzy sets facilitate the expression of partial truths, thereby providing a more authentic reflection of complex, real-world scenarios (Toledo-Castro et al., 2018; Biber et al., 2021).

This capability is particularly relevant in the context of Sustainable Forest Management (SFM) in India, a domain often hampered by the dearth of exhaustive and precise data (Pourghasemi et al., 2016; Massoud et al., 2019). Given that decision-making in Indian forestry often grapples with ambiguities—ranging from ecosystem health to stakeholder interests—the application of fuzzy set theory serves as a robust mechanism for crafting informed strategies by allowing the integration of qualitative and quantitative data in a unified analytical model (Juvanhol et al., 2021; Ghosh & Dey, 2021). Thus, fuzzy sets significantly augment the sophistication and adaptability of the decision-making apparatus, thereby enriching the landscape of sustainable forestry management in the subcontinent.

In Figure 2, a Triangular Fuzzy Number (TFN) is visually represented and symbolically denoted by the tuple (l, m, u). Here, 'l' signifies the minimum plausible value, 'm' stands for the most likely or optimistic value, and 'u' captures the maximum conceivable value, each characterizing a specific fuzzy occurrence.

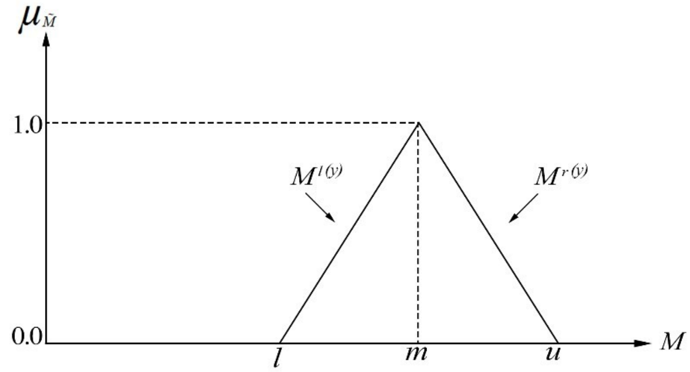

Figure 6.7. Triangular Fuzzy Number M̃

All TFNs have linear representations on both their left and right sides, allowing their membership functions to be described.

$$\mu\left(x \mid \tilde{M}\right)=\begin{cases} 0, & x<1, \\ (x-l)/(m-l), & l \leq x \leq m, \\ (u-x)/(u-m), & m \leq x \leq u, \\ 0, & x>u \end{cases}$$

Any degree of membership may be expressed as a fuzzy number by comparing its left and right representations:

$\tilde{M}=(M^{l(y)},M^{r(y)}=(l+(m-l)y,\, u+(m-u)y)\ y\in[0,1]$

Where l(y) and r(y) denote the fuzzy number's left and right sides, respectively.

Fuzzy analytic hierarchy process

The Fuzzy Analytic Hierarchy Process (AHP) is essentially a refinement of classical AHP, with its methodology enriched by Fuzzy Set Theory (Haidara et al., 2019; Feizizadeh et al., 2015). This integration of Fuzzy Set Theory into AHP provides an advanced and nuanced approach that encapsulates the ambiguities and complexities inherent in decision-making (Güngöroğlu, 2017; Akay et al., 2018). In comparison to classical Fuzzy Theory, which deals primarily with the fuzziness of individual elements, Fuzzy AHP provides a holistic view by considering multiple criteria and alternatives, thereby offering superior decision-making capabilities (Roshani et al., 2022; Bayram, 2021).

The role of Fuzzy AHP in the realm of multiple criteria decision-making (MCDM) under uncertainty is transformative. It furnishes a mathematical rigor that accommodates linguistic variables, imprecise data, and human subjectivity (Salehnasab et al., 2016; Mostafa et al., 2022). Particularly in the context of Sustainable Forest Management (SFM) in India, the Fuzzy AHP's relevance is invaluable. Given the subcontinent's ecological diversity and socio-political complexities, decision-making in SFM often grapples with ambiguities and uncertainties (Pourghasemi et al., 2016; Liu et al., 2017). Here, Fuzzy AHP provides a scientific grounding for prioritizing competing interests and conflicting criteria, thereby aiding in the formulation of more sustainable and context-sensitive policies (Kacem et al., 2021; Parajuli et al., 2023).

Furthermore, the application of Fuzzy AHP extends well beyond forestry and environmental sciences. It is increasingly being adopted in a myriad of fields such as healthcare, engineering, economics, and logistics, attesting to its versatility and effectiveness in dealing with multifaceted and ill-defined problems (Haidara et al., 2019; Kacem et al., 2021). Thus, Fuzzy AHP serves as a linchpin in contemporary decision-making paradigms, bridging the gap between mathematical exactitude and the nuanced uncertainties of real-world scenarios.

Various fuzzy AHP methods exist in scholarly literature, each with its distinctive advantages and limitations. Methods utilizing Triangular Fuzzy Numbers (TFN) in the pairwise comparison matrix offer a straightforward representation of uncertainty but may lack the robustness needed for more complex scenarios (Pourghasemi et al., 2016; Liu et al., 2017). Meanwhile, techniques employing trapezoidal fuzzy numbers provide greater flexibility by incorporating a range of plausible outcomes (Feizizadeh et al., 2015; Zabihi et al., 2020). A fuzzy prioritization method takes a different tack by simplifying the complex relationships among criteria into an easily interpretable set of priorities (Kacem et al., 2021; Mafi-Gholami et al., 2015).

Given its particular applicability to Criteria and Indicators (C&I) systems in Sustainable Forest Management (SFM) in the Indian setting, this work used Chang's (1996) extent analysis approach.

The rationale for this choice lies in the method's inherent ability to comprehensively consider both quantitative and qualitative indicators. Chang's method adds a layer of precision that is pivotal for an ecologically diverse and socio-politically complex landscape like India (Parajuli et al., 2023; Tiwari et al., 2021).

Fuzzy group Analytic Hierarchy Process

The AHP methodology is relevant for both single and collective decision-making scenarios, as underscored by Mohammadi Samani et al. (2010). When applied to group-based decisions, it becomes crucial to amalgamate the preferences of various experts into a collective standpoint, as noted by Pokhriyal et al. (2020). A plethora of aggregation techniques have been discussed in scholarly works (Unver & Ergenc, 2021). Among these, two methods have gained prominence for their utility in collective decision-making within AHP: one focuses on unifying individual judgments (AIJ), and the other centers on consolidating individual priorities (AIP), according to Piran et al. (2013). For the purpose of this study, the AIJ approach was selected.

In the AIJ approach, each participant independently carries out their own set of pairwise assessments. Subsequently, a unified evaluation for each element in the comparison grids is derived through the application of the geometric mean technique (Sivrikaya & Küçük, 2022). This particular arithmetic operation aids in synthesizing a group judgment matrix by pooling together the individual matrices (Pourghasemi et al., 2016). The employment of geometric mean calculations as a tool for amalgamating collective viewpoints is a recurrent practice in AHP implementations involving group scenarios (Pleşca et al., 2019; Kumari & Pandey, 2020).

The fuzzy AHP serves as a significant advancement over its conventional AHP predecessor (Lepetu, 2012; Ljubomir et al., 2019). Scholars have recognized the value of the geometric mean in addressing challenges related to decision synthesis and aggregation within the fuzzy AHP framework (Pourghasemi et al., 2016).

The Fuzzy Group Analytic Hierarchy Process methodology, as applied in the current study, leverages the strengths of both fuzzy logic and the group decision-making capabilities inherent in AHP. By integrating the Fuzzy AHP with a group-based decision-making approach, the study addresses the complex and often subjective nature of evaluating criteria and indicators for sustainable forest management. The adoption of the Aggregation of Individual Judgments (AIJ) method, as highlighted by Mohammadi Samani et al. (2010) and supported by Pokhriyal et al.

(2020), underscores the importance of synthesizing diverse expert opinions into a coherent evaluation framework.

The utilization of the geometric mean technique for amalgamating individual assessments, as advocated by Sivrikaya & Küçük (2022) and Pourghasemi et al. (2016), is particularly noteworthy. This mathematical approach not only facilitates the consolidation of varied expert inputs but also ensures that the aggregated judgments are representative of the collective wisdom of the group. This is crucial in the context of sustainable forest management, where decisions must account for a wide range of ecological, social, and economic factors, each with its inherent uncertainties and subjective interpretations.

Furthermore, the application of the fuzzy AHP enhances the decision-making process by accommodating the nuances and ambiguities that traditional AHP might overlook. The acknowledgment of the geometric mean's value in decision synthesis within the fuzzy framework, as discussed by Pleșca et al. (2019) and Lepetu, Ljubomir et al. (2019), highlights the method's robustness in handling the complexities of multi-criteria decision-making. In the present study, to consolidate individual evaluations into a collective outcome, calculations involving geometric mean and fuzzy numbers were employed, as delineated in the ensuing equation:

$$l_{ij} = \left(\prod_{k=1}^{k} l_{ijk} \right)^{1/k}, m_{ij} = \left(\prod_{k=1}^{k} m_{ijk} \right)^{1/k}, u_{ij} = \left(\prod_{k=1}^{k} u_{ijk} \right)^{1/k}$$

Implementing Fuzzy AHP for Indicators and Criteria Weighting

Subsequently, the consolidated decision matrix for the primary criteria and associated computational steps are presented. Moreover, the assimilation of expert evaluations concerning the inaugural criterion is detailed as a sample illustration to clarify how these collective decision matrices were formulated (Refer to Table 6.13). As for the sub-criteria, only the outcomes of the calculations will be shown. The methodologies for amalgamating and computing both the sub-criteria and primary criteria have already been elaborated upon in the sections discussing fuzzy analytic hierarchy process and fuzzy group AHP.

	C_1										
	Expert 1	**Expert 2**	**Expert 3**	**Expert 4**	**Expert 5**	**Expert 6**	**Expert 7**	**Expert 8**	**Expert 9**	**Expert 10**	**Aggregated Group Decision**
C_1	(1.00, 1.00, 1.00)	(1.00, 1.00, 1.00)	(1.00, 1.00, 1.00)	(1.00, 1.00, 1.00)	(1.00, 1.00, 1.00)	(1.00, 1.00, 1.00)	(1.00, 1.00, 1.00)	(1.00, 1.00, 1.00)	(1.00, 1.00, 1.00)	(1.00, 1.00, 1.00)	(1.00, 1.00, 1.00)
C_2	(0.67, 1.00, 1.50)	(1.50, 2.00, 2.50)	(1.00, 1.00, 1.00)	(1.50, 2.00, 2.50)	(1.50, 2.00, 2.50)	(1.00, 1.00, 1.00)	(3.50, 4.00, 4.50)	(2.50, 3.00, 3.50)	(2.50, 3.00, 3.50)	(2.50, 3.00, 3.50)	(1.62, 1.97, 2.32)
C_3	(0.67, 1.00, 1.50)	(0.29, 0.33, 0.40)	(0.29, 0.33, 0.40)	(0.40, 0.50, 0.67)	(0.40, 0.50, 0.67)	(0.40, 0.50, 0.67)	(2.50, 3.00, 3.50)	(2.50, 3.00, 3.50)	(2.50, 3.00, 3.50)	(2.50, 3.00, 3.50)	(0.82, 1.01, 1.27)

Table 6.14 Aggregation of experts' judgments on the first criterion

To generate the unified group decision matrix, identical procedures were executed across all main and subordinate criteria, with the resulting matrix presented in Table 6.13. Subsequent computations delineated in the pages that follow draw upon the information contained in Table 6.13.

	C_1	C_2	C_3
C_1	(1.00, 1.00, 1.00)	(0.43, 0.51, 0.62)	(0.79, 0.99, 1.22)
C_2	(1.62, 1.97, 2.32)	(1.00, 1.00, 1.00)	(1.46, 1.78, 2.12)
C_3	(0.82, 1.01, 1.27)	(0.47, 0.56, 0.68)	(1.00, 1.00, 1.00)

Table 6.15 Aggregated main criteria group decision matrix

Subsequent to establishing the fuzzy pairwise comparison matrix, the determination of criterion weights is performed using fuzzy AHP. Within this framework, the initial step involves the computation of synthetic values. These values are ascertained in alignment with the primary objective, employing equations three through six, and relying on the data presented in Table 6.14.

$$S_{c1} = (2.22, 2.50, 2.84) \otimes (0.0891, 0.1018, 0.1164) = (0.20, 0.25, 0.33)$$

$$S_{c2} = (4.08, 4.75, 5.44) \otimes (0.0891, 0.1018, 0.1164) = (0.36, 0.48, 0.63)$$

$$S_{c3} = (2.29, 2.57, 2.95) \otimes (0.0891, 0.1018, 0.1164) = (0.20, 0.26, 0.34)$$

The following is a formula for determining the probabilities of these values:

$$V(S_{c1} \geq S_{c2}) = 0.0000,\ V(S_{c1} \geq S_{c3}) = 0.94$$

$$V(S_{c2} \geq S_{c1}) = 1.0000,\ V(S_{c2} \geq S_{c3}) = 1.0000$$

$$V(S_{c3} \geq S_{c1}) = 1.0000,\ V(S_{c3} \geq S_{c2}) = 0.0000$$

To determine priority weights:

$$d'(c_1) = min(0, 0.94) = 0$$

$$d'(c2) = min(1, 1) = 1$$

$$d'(c_3) = min(1, 0) = 0$$

The vector containing priority weights is (0,1,0). After these numbers are normalized, the priority weights with regard to the primary objective are computed as (0,1,0). In other words, the environmental criterion is completely paramount, with a weight of "1" (100 percent crucial), and the social and economic factors are completely irrelevant.

Table 14, included in the findings and discussion section, indicates the priority weights for each criterion and sub-criterion.

6.13 Results and discussion

Using the fuzzy AHP technique, this article ranked the parameters impacting sustainable forest management in India. Table 6.15 displays the findings of the analysis, which included three criteria and thirteen sub-criteria.

Criteria	**Indicators (Sub Criteria**	**Local Weight**	**Global Weight**
Social (0)	Recreational and Leisure area	0.00	0
	Traditional uses	0.30	0
	Landscape	0.02	0
	Employment	0.68	0

Environmental (1)	Climate stabilization	0.00	0.00
	Soil Enrichment	0.13	0.13
	Regulation of water cycles	0.29	0.29
	Improved Biodiversity	0.17	0.17
	Purification of air	0.12	0.12
	CO2 Sink	0.29	0.29
Economic (0)	Timber	0.00	0
	Non-wood forest products	0.30	0
	Employment	0.70	0

Table 6.16: The results Fuzzy analytic hierarchy process

The analysis presented in Table 14 utilizes the fuzzy Analytic Hierarchy Process (AHP) to assess the factors influencing sustainable forest management in India, focusing on three main criteria: Social, Environmental, and Economic. The results offer a unique perspective on the relative importance of these criteria in the context of sustainable forest management within the country.

According to the findings, the Environmental criterion received a global weight of 1, indicating it is considered paramount in the context of sustainable forest management in Madhya Pradesh, India. This outcome underscores the critical importance of ecological considerations in managing forests sustainably. It suggests that factors related to the environment, such as climate stabilization, soil enrichment, water cycle regulation, biodiversity improvement, air purification, and CO2 sequestration, are viewed as the most crucial aspects of forest management. The same findings have been revealed in the Indian context, where it has been revealed that a number of authors (Rai et al., 2012; Amarnath, Babar & Murthy, 2017; Kumar et al., 2021) have emphasized environmental contexts. This prioritization reflects a recognition of the intrinsic value of forests in maintaining ecological balance and providing ecosystem services essential for life and human well-being.

On the other hand, both the Social and Economic criteria received a global weight of 0. This result indicates that, within the framework of this analysis, these two criteria are considered to have no significant impact on sustainable forest management decisions in comparison to environmental concerns. The assignment of a zero weight to Social and Economic criteria suggests that at least in the context of this study, activities or benefits related to recreational areas, traditional uses, landscape aesthetics, employment in the forestry sector, timber production, and non-wood forest products are not prioritized over environmental considerations (Yadav & Dugaya, 2013; Saigal et al., 2013).

The emphasis on environmental criteria reflects a broader trend in global forest management practices, where ecological health and sustainability are increasingly becoming the primary focus of decision-making processes. The detailed analysis of the local weight results for the sub-criteria under the Social, Environmental, and Economic categories offers an insightful perspective into the priorities for sustainable forest management in India.

Starting with the Social criteria, the significant local weight assigned to 'Employment' (0.68) underscores the crucial role of forestry in providing livelihoods. This emphasis aligns with the observations by Yadav and Dugaya (2013), who highlighted the socio-economic importance of forests in supporting rural livelihoods through employment opportunities. However, the minimal weights allocated to the 'Recreational and Leisure area' (0.00) and 'Landscape' (0.02) suggest a lesser focus on these aspects within the social dimension of forest management. This could reflect a prioritization of tangible benefits over aesthetic or recreational values, a perspective supported by Dwivedi et al. (2009), indicating a primary concern with livelihood and economic sustenance over leisure activities in forest policy.

In the Environmental category, the equal highest local weights given to 'Regulation of water cycles' and 'CO2 Sink' (both 0.29) reflect a strong emphasis on the ecosystem services provided by forests. This prioritization is supported by Jafari et al. (2018) and Kumar et al. (2021), who underscore the critical role of forests in climate regulation and water cycle maintenance. The importance placed on 'Improved Biodiversity' (0.17) and 'Soil Enrichment' (0.13) further underscores a comprehensive approach to environmental sustainability, recognizing the multifaceted benefits of forests in ecological balance and soil health, as discussed by Tewari (2015).

Conversely, the Economic criteria's focus on 'Employment' (0.70) over 'Timber' (0.00) and 'Nonwood forest products' (0.30) reveals a nuanced understanding of forest value. This suggests a shift towards recognizing the broader economic benefits of forests beyond timber extraction, resonating with Iyengar & Bajaj (2011) and Boafo (2013), who advocate for the economic valuation of forests in terms of their full range of products and services, including employment generation.

The analysis indicates a significant emphasis on environmental factors over social and economic considerations. This trend reflects a growing acknowledgment of the paramount importance of ecological integrity in forest management practices. The prioritization of environmental criteria aligns with global sustainability goals and is supported by literature indicating a shift in forestry management towards ecological conservation and climate change mitigation (Datta and Chatterjee, 2012; Chattopadhyay & Datta, 2010). Such a focus is critical in the context of India, where the pressures of climate change, biodiversity loss, and water scarcity necessitate an environmentally centric approach to forest management (Dwivedi et al., 2009).

The findings from the fuzzy AHP analysis present a compelling narrative about the priorities for sustainable forest management in India, highlighting a clear prioritization of environmental considerations over social and economic factors. This prioritization is reflective of a broader recognition of the essential role that ecological integrity plays in the sustainable management of forests. The global weight assigned to the Environmental criterion (1) underscores the paramount importance attributed to ecological concerns, aligning with the observations made by Rai et al. (2012), Amarnath, Babar & Murthy (2017), and Kumar et al. (2021), who have similarly emphasized the critical nature of environmental contexts in forest management.

For policymakers in India, these findings offer a clear directive: sustainable forest management policies must prioritize environmental sustainability to maintain ecological balance and provide essential ecosystem services. This entails a strategic focus on factors such as climate stabilization, soil enrichment, water cycle regulation, biodiversity improvement, air purification, and CO2 sequestration. Such a focus not only addresses the immediate ecological challenges but also contributes to the broader global sustainability goals, highlighting the intrinsic value of forests beyond their economic and social utilities.

The assignment of a zero global weight to both Social and Economic criteria suggests a nuanced understanding of sustainable forest management, one that recognizes the indispensable value of ecological health over immediate economic gains or social benefits. This perspective is supported by Yadav & Dugaya (2013) and Saigal et al. (2013), who acknowledge the socio-economic contributions of forests but suggest that these are currently secondary to environmental sustainability goals in policy formulation. This doesn't imply that social and economic factors are irrelevant but indicates a strategic decision-making approach where environmental conservation is paramount. For policymakers, this prioritization has profound implications. Firstly, it necessitates the integration of environmental sustainability into all aspects of forest management policies. Policies should be crafted to enhance the ecological functions of forests, reinforcing their role in climate regulation, biodiversity conservation, and provision of ecosystem services. Moreover, this approach requires the establishment of robust monitoring and evaluation mechanisms to assess the effectiveness of environmental conservation efforts continually.

Secondly, while environmental considerations are paramount, the findings also highlight the importance of not overlooking the socio-economic dimensions of forest management. The significant local weight assigned to 'Employment' under both Social and Economic criteria underscores the critical role forests play in livelihood sustenance. Policymakers must, therefore, ensure that environmental policies are complemented by socio-economic strategies that support the livelihoods of communities dependent on forests. This might involve promoting sustainable forest-based livelihoods, enhancing access to non-wood forest products, and ensuring equitable benefit-sharing mechanisms.

Furthermore, the emphasis on environmental sustainability should not preclude the development and implementation of integrated management approaches that balance ecological integrity with socio-economic needs. Such approaches could include community-based forest management practices that involve local communities in conservation efforts, thereby aligning environmental objectives with social and economic development goals.

In conclusion, the findings from this analysis signal a clear imperative for policymakers in India: to reorient sustainable forest management policies towards environmental conservation as a foundational pillar. This requires not only a steadfast commitment to ecological sustainability but also a nuanced approach that integrates socio-economic considerations into forest management practices. By doing so, India can advance towards realizing sustainable forest management that harmonizes ecological, social, and economic objectives, thereby contributing to national and global sustainability targets. Policymakers are tasked with navigating this complex terrain, crafting policies that are both forward-looking and grounded in the realities of India's diverse socioecological landscape.

6.14 Conclusion

The analysis conducted using the fuzzy Analytic Hierarchy Process (AHP) to evaluate the factors affecting sustainable forest management in Madhya Pradesh, India reveals a compelling prioritization of environmental considerations over social and economic factors. This prioritization underscores the critical importance attributed to ecological integrity and ecosystem services in the management of Indian forests. The findings, which emerge from a comprehensive assessment of three main criteria and thirteen sub-criteria, offer a nuanced understanding of sustainable forest management that significantly leans towards environmental sustainability.

The Environmental criterion, with a global weight of 1, emerges as the paramount concern, reflecting an acute awareness of the indispensable role forests play in maintaining ecological balance, regulating climate, enhancing biodiversity, enriching soil, purifying air, and acting as CO_2 sinks. This emphasis is well-supported by the literature, with various studies (Rai et al., 2012; Amarnath, Babar & Murthy, 2017; Kumar et al., 2021) highlighting the criticality of environmental factors in forest management within the Indian context. Such a focus is indicative of a strategic orientation towards leveraging forest management as a tool for addressing broader environmental challenges, including climate change and biodiversity conservation.

Conversely, the Social and Economic criteria, both assigned a global weight of 0, are deemed to have negligible impact on sustainable forest management decisions relative to environmental concerns. This does not diminish the importance of forests in providing livelihoods and economic benefits but indicates a strategic decision to prioritize ecological considerations at the potential expense of immediate social and economic benefits. This finding resonates with Yadav & Dugaya (2013) and Saigal et al. (2013), who acknowledge the socio-economic contributions of forests but suggest that these are currently secondary to environmental sustainability goals in policy formulation and implementation.

The detailed analysis of sub-criteria further illustrates the specific areas of focus within each main criterion. The significant weight given to 'Employment' under both Social and Economic criteria highlights the recognition of forestry as a vital source of livelihood, despite the overall lower prioritization of these criteria. Meanwhile, the Environmental sub-criteria emphasize the multifaceted roles forests play in ecological processes and climate regulation, aligning with global sustainability objectives and the urgent need for environmental conservation highlighted in the literature (Datta and Chatterjee, 2012; Chattopadhyay & Datta, 2010; Dwivedi et al., 2009).

Based on our research findings, there is a requirement for increased focus on achieving a balance between the interrelatedness of the three categories of sustainable forest management, notwithstanding the commonly held belief that the ecological aspect is of utmost importance. The effective deployment of C&I systems necessitates a meticulously orchestrated strategy that recognizes compromises and endeavors to achieve equilibrium among environmental conservation, fair distribution of resources, and financial feasibility. In the following section, we will present specific suggestions derived from our research, with the goal of strengthening the implementation of C&I Indicator systems in India to advance sustainable forest management.

6.15 Recommendations

Drawing from our research results, we suggest the subsequent recommendations to enhance the practice of sustainable forest management (SFM) in India, with a specific emphasis on the execution of Criteria and Indicators (C&I) frameworks:

Enhance Stakeholder Participation in the Bhopal-India Process: The process has significantly contributed to SFM in India, however, the full spectrum of stakeholder perspectives needs to be represented. Therefore, we recommend facilitating more inclusive dialogues and capacity building initiatives, especially for marginalized and forest-dependent communities, ensuring their voices are heard and their rights are respected. This step is critical to balance the trade-offs between the ecological, social, and economic categories. Enhancing stakeholder participation, especially from marginalized and forest-dependent communities, is pivotal for a holistic approach to Sustainable Forest Management (SFM). By integrating diverse perspectives, particularly those directly impacted by forest policies, a more equitable and comprehensive management strategy can be developed (Yadav & Dugaya, 2013). This inclusive dialogue ensures that trade-offs between ecological, social, and economic categories are navigated with a nuanced understanding of ground realities, promoting policies that are both environmentally sustainable and socially equitable. Such an approach not only respects the rights of local communities but also enriches the decision making process with grassroots insights, fostering policies that are more effectively tailored to local needs and conditions.

Invest in Ecological Monitoring and Conservation: Given the primacy of the ecological category in SFM as revealed in the survey, there should be more substantial investments in forest health monitoring systems and conservation initiatives. Ensuring the ecological integrity of the forests can help support social and economic benefits in the long term. Investing in ecological monitoring and conservation initiatives addresses the primary concern of maintaining forest health and integrity, as highlighted in the analysis (Kumar et al., 2021). Strengthening these systems supports the ecological foundation upon which social and economic benefits are built, ensuring sustainable outcomes in the long term. Enhanced monitoring enables the early detection of ecological degradation, facilitating timely interventions. Conservation initiatives contribute to the preservation of biodiversity, water resources, and soil health, thereby supporting ecosystem services crucial for human well-being and climate regulation. This strategic focus on ecological integrity is essential for sustaining the multifunctional roles of forests in supporting livelihoods and economic activities.

Promote Sustainable Economic Opportunities: While the ecological dimension is critical, policymakers should not overlook the economic category. It is recommended to encourage sustainable economic activities, such as ecotourism and responsible timber harvesting, which can provide income and employment to local communities, while also contributing to conservation efforts. Promoting sustainable economic activities such as ecotourism and responsible timber harvesting aligns with the need to integrate economic viability with ecological conservation (Iyengar & Bajaj, 2011; Boafo, 2013). This approach provides a pathway for local communities to benefit economically while incentivizing the preservation of forest ecosystems. Sustainable economic opportunities can create a positive feedback loop, where economic benefits derived from the forest encourage local and national stakeholders to invest in conservation efforts. This balance between exploitation and conservation is crucial for long-term sustainability, ensuring that forest resources continue to support economic development without compromising ecological integrity.

Strengthen the C&I Systems: There is a need to continuously review and strengthen the C&I systems based on changing socio-economic and environmental contexts. Policymakers should consider revising or adding indicators as necessary to better reflect current challenges and emerging issues in forest management. Continuously reviewing and strengthening the Criteria and

Indicators (C&I) systems for SFM is vital for adapting to the evolving socio-economic and environmental landscapes (Dwivedi et al., 2009). By revising and updating the indicators, policymakers can ensure that the C&I systems remain relevant and effective in addressing current challenges and emerging issues. This proactive approach enables the monitoring and management systems to reflect the latest scientific understanding and societal values, facilitating more informed and responsive forest management practices. Strengthening the C&I systems ensures that SFM policies are grounded in accurate, up-to-date information, enhancing their effectiveness in achieving sustainable outcomes.

Promote Awareness and Education: Lastly, there should be a concerted effort to raise awareness about SFM and the importance of C&I systems among various stakeholders, including policymakers, forest managers, local communities, and the general public. This could be achieved through educational programs, workshops, and media campaigns. Raising awareness and educating various stakeholders about the principles of SFM and the role of C&I systems is critical for building a supportive environment for sustainable forest management (Tewari, 2015). Awareness campaigns and educational programs can demystify SFM concepts, making them more accessible to the public, policymakers, and forest managers. This increased understanding fosters greater appreciation of the importance of forests and the need for sustainable management practices, potentially leading to wider support for conservation efforts. Educating stakeholders about the benefits and challenges of SFM promotes more informed participation in forest management decisions, contributing to more sustainable and community-supported outcomes.

These recommendations, if implemented effectively, could facilitate a more balanced approach to SFM in India, better managing the interdependence and trade-offs between the ecological, social, and economic categories, ultimately leading to healthier and more resilient forest ecosystems.

Summary of the chapter

Many hierarchy approaches have been established for the SFM idea owing to its complicated nature (Jafari et al., 2018). These frameworks include several criteria and indicators (C&I) that are essential for monitoring, measuring, and evaluating management strategies (Martín-Fernández & MartinezFalero, 2018). C&I provides a scientifically backed framework that may serve as the foundation for policy choices (Hall, 2001). Despite the United Nations' efforts, there is currently no international consensus on the assessment or criteria and indicators for Sustainable Forest

Management (SFM) due to its complexity. However, countries and regions have established a foundational framework comprising 7 criteria and 65 indicators (Jafari et al., 2018; Mohammadi & Limaei, 2018; Ness et al., 2007; Reynolds et al., 2007).

This study explores the complex processes involved in setting up criterion and indicator (C&I) systems for SFM in India. In the context of assessing C&I system for SFM in India, the application of this methodology is used. In the subsequent sections, we delve into the rationale for the study, aims and objectives, followed by a comprehensive exploration of the Bhopal-India process, C&I systems in India and other countries, and the innovative application of fuzzy logic and AHP in creating a sound SFM system. This study endeavors to fill a crucial gap in the existing literature on Indian SFM by employing FAHP as a sophisticated tool for evaluating and recalibrating C&I. By embracing FAHP's capacity for handling complexity and ambiguity, the study aims to provide actionable insights that can inform and elevate future SFM strategies in India (Ljubomir et al., 2019; Bayram, 2021; Salehnasab et al., 2016).

It is pertinent to scrutinize the limitations of AHP in handling complex, multi-dimensional problems that pervade the sphere of SFM. Notably, AHP often falls short in addressing the inherent vagueness and subjectivity associated with ecological and socio-economic factors (Haidara et al., 2019; Feizizadeh et al., 2015). While it provides a structured framework for evaluating multiple criteria, its rigidity limits its capability to incorporate the nuanced complexities often encountered in SFM decision-making (Kacem et al., 2021; Parajuli et al., 2023).

The unique feature that distinguishes this study is the application of FAHP in evaluating Criteria and Indicators (C&I) systems specific to the Indian context of sustainable forestry. FAHP ameliorates the limitations of AHP by integrating fuzzy set theory, thereby allowing for a more flexible, context-sensitive assessment that can accommodate uncertainty and imprecision (Pourghasemi et al., 2016; Liu et al., 2017). This adaptation of FAHP transcends conventional methodologies by offering a more holistic, nuanced approach to evaluating the complex landscape of SFM criteria and indicators.

Chapter 7: Conclusion, policy recommendations and future direction of the research

7.1 Conclusion

This chapter provides an overall conclusion of the thesis. The chapter reflects on the research questions and their analysis through various chapters of the thesis. The thesis successfully forms a substantial aspects of sustainable forest management covering from understating the forests (in terms of their benefits, importance concerns and successful strategies to manage them), the impact on forests along with the governance challenge in managing these resources in a sustainable manner. This chapter gives a quick review of the outcomes their interpretation and challenges ahead, mentioned in previous chapters.

Forest ecosystems encompass the intricate interrelationships among the various plant, animal, and microbial species inhabiting a wooded region. The ecosystems in question exhibit distinct features such as a dense tree canopy, a rich variety of flora and fauna, and efficient cycling of nutrients and water, as noted by Zhang et al. (2017). The urgency of sustainability is underscored by various environmental challenges such as climate change (Costanza et al., 2016) and biodiversity loss (Lu et al., 2015). To address these issues, concerted and immediate action is required (Sachs et al., 2019; Sachs, 2012). The SDGs offer a comprehensive framework for taking action, with a particular emphasis on the pressing requirement for achieving a harmonious equilibrium between human development and the health of the planet.

In the context of addressing the complexities of forest conservation and sustainability, this thesis posited several critical research questions aimed at dissecting the multifaceted interactions between climatic and non-climatic factors and their impact on forest loss in India. At the forefront, we sought to ascertain whether variations in climatic elements such as temperature and precipitation, alongside non-climatic variables including CO_2 emissions, industrialization, and agricultural practices, significantly influence forest degradation. Furthermore, the investigation delved into the repercussions of these climatic and non-climatic forces on India's forest ecosystems, aiming to unravel the nuanced ways in which they affect forest health and stability. Recognizing the pivotal role of governance, another dimension of our inquiry focused on the contributions of institutional frameworks to the promotion of sustainable forest management practices within the country. This encompasses an examination of how regulatory bodies, policies, and community involvement coalesce to foster or impede the preservation of forest resources. Additionally, the research scrutinized the function of forests within the broader ambit of sustainable development in India, probing their contribution to ecological balance, economic growth, and social well-being. Lastly, the potential of a criteria and indicator system for sustainable forest management was evaluated for its efficacy in informing policy decision-making processes. This comprehensive exploration aimed not only to identify the determinants of forest loss but also to spotlight effective strategies and mechanisms that can bolster forest conservation efforts, thereby contributing to the achievement of sustainable development goals in India.

- Summary and Main Contribution to Chapter 2 Literature Review

The study conducted an extensive literature review on the context of understanding the resources. To effectively counteract the adverse effects of climate change on forest ecosystems and enhance their resilience, the deployment of robust adaptive measures and refined forest management strategies is imperative. Such strategies encompass a broad spectrum, including the restoration of forests, the facilitated migration of tree species to more suitable habitats, the modification of traditional forest management practices, and the augmentation of genetic diversity within forest populations (Mutoko et al., 2015; Tebkew & Atinkut, 2022). The successful implementation of Sustainable Forest Management (SFM) and the achievement of the targets set under Sustainable Development Goal (SDG) 15.2 hold considerable promise for addressing the intertwined environmental and socio-economic challenges confronting forest ecosystems. This discourse underscores the necessity of advancing sustainable forest utilization and management practices that simultaneously safeguard biodiversity, contribute to climate change mitigation efforts, and enhance the quality of life for communities dependent on forest resources.

Nonetheless, the realization of SFM's potential is not without its hurdles. These include the necessity of reconciling multiple, sometimes conflicting objectives and the integration of SFM principles into broader land-use planning and policy frameworks (Sikka et al., 2013; Talty et al., 2020). The ongoing refinement of the SFM concept and its practical applications, informed by current research, continuous monitoring, and localized experiences, is vital for the evolution of forest management paradigms (Tebkew & Atinkut, 2022). It is crucial for global, national, and local policies to acknowledge and bolster the multifaceted role of forests, promoting the incorporation of SFM principles into comprehensive land-use planning and decision-making processes. Aligning economic incentives with the objectives of SFM—through mechanisms such as payment for ecosystem services and green certification schemes—is essential for fostering sustainable forest management practices (Hjerpe & Hussain, 2016).

Moreover, recent case studies illuminate the efficacy of adopting a landscape approach to forest management. This perspective integrates forests within the broader context of land-use systems, including agriculture, infrastructure, and human settlements, facilitating the management of tradeoffs and synergies among diverse land uses. Such an approach ensures that all sectors contribute towards the collective ambition of sustainability, underscoring the necessity of a cohesive, comprehensive, and integrated strategy that appreciates and leverages the multifunctional value of forests for the planet and future generations (Casipit et al., 2020; Talty et al., 2020).

- Summary and Main Contribution to Chapter 3: Impact of climatic and non-climatic factors on forest loss in India: A theoretical and empirical review

The first research question this study investigated was, "Is there any evidence that climatic factors and non-climatic factors like temperature, precipitation, CO2 emissions, industrialization and agriculture have an impact on forest loss in India?" the study has found that the impacts of climate change on forest ecosystems are significant. It affect everything, such as species distribution and forest structure. Increased frequency of forest disturbances, such as wildfires and pest outbreaks are also crucial concerns. Despite these challenges, forests display a degree of natural resilience, and human interventions have shown promise in enhancing this resilience (Cao et al., 2021; Gu et al., 2022). The coefficient of temperature anomaly is positive but insignificant at 1% significance level. It implies that temperature anomaly deteriorates the forest coverage in India. Similarly, rainfall anomaly has a positive sign and is significant at 1% level of significance (Long et al., 2014). Rainfall anomaly also leads to a decline in forest coverage in India.

The complex interplay between CO2 emissions and forest ecosystems has revealed that elevated CO2 levels can have a broad spectrum of impacts on forests. From altering plant growth and productivity to influencing biodiversity and forest health, CO2 emissions are reshaping our forests in significant ways (Delphin et al., 2016; Bai et al., 2019). These changes can, in turn, affect the role of forests as carbon sinks and regulators of atmospheric CO2, possibly creating feedback loops that could either amplify or mitigate climate change effects. DOLS findings demonstrated that CO_2 significantly degraded forest in India.

The impact of agricultural practices on forest ecosystems is significant. This review has highlighted various direct and indirect effects, from deforestation and habitat fragmentation to soil degradation, water pollution, and altered hydrological cycles (Du & Huang, 2017). It has also revealed that agricultural expansion often occurs at the expense of forest ecosystems, causing substantial loss of biodiversity. However, the adoption of sustainable practices and well-planned land-use strategies can mitigate these impacts.

The phenomenon of urbanization, while bringing numerous benefits such as economic growth and societal development, presents significant challenges to forest ecosystems. This chapter has underscored the numerous factors driving urbanization in India, including population growth, economic development, industrialization, and rural-to-urban migration, each of which has direct and indirect impacts on forests (Seto, Parnell & Elmqvist, 2013). The ecological impacts of urbanization on forest ecosystems are manifold. Urban expansion often results in habitat loss and fragmentation, causing profound changes in biodiversity and species composition.

This habitat destruction can lead to the disappearance of native species and the proliferation of invasive ones, thereby altering the structure and function of forest ecosystems. Furthermore, urbanization can bring about shifts in ecosystem functions and processes and contribute to pollution and other environmental stressors, exacerbating the pressures on forest ecosystems. Simultaneously, urbanization can also have substantial social and economic repercussions. It can alter human-wildlife interactions, with the potential for increased human-wildlife conflict. It can impact the cultural and recreational values of forests as natural spaces become increasingly urbanized. Moreover, it can affect forest-based livelihoods and economic benefits as forests are depleted or their resources are overexploited.

- Summary and Main Contribution to Chapter 4: Institutional analysis for sustainable forest management in India

The second research question was, "What role the institutions play in sustainable forest management In India?" The role of institutions in sustainable forest management (SFM) in India reveals that institutions play pivotal roles across various aspects, from policy formulation to community engagement and research. Institutions foster policy directions, govern forest conservation efforts, and champion research and education that further underpin SFM. The political and legal landscape significantly affects SFM in India. Legislation, political decision making, and judiciary interpretations can either enhance or hinder SFM efforts, emphasizing the importance of aligned legal provisions and proactive governance.

Broadly, while the central institutes have the responsibility of determining the overall policy frame, the sub-national institutes are mainly involved in implementation. Thus, this system attempts to minimize transaction costs by providing sufficient scope for decentralized governance of forests. At the same time, the central government has overriding powers to avoid unstable competition and institute mechanisms to resolve inter-state disputes. The institutions of JFM and village forest committees have enhanced the stake of the local population in the development of forestry. However, decentralized solutions may also lead to power shifts to the elite group unless adequate safeguards are taken. This problem is difficult to acknowledge and report. Thus the most vulnerable population dependent on forestry remain vulnerable. This is in contradiction to the concept of sustainable forest management.

Different levels of government, from national to state and local, influence SFM in distinctive ways (Springate-Baginski and Blaikie, 2013; Cheng et al., 2019). Their roles, limitations, and success stories reflect the complex governance structure that navigates India's diverse forest landscapes.

- Summary and Main Contribution to Chapter 5: Synergies between forestry and sustainable development goals: Identifying effective actions

The third research question was, “What role do forests have in sustainable development in India?” The study that was done across all of the Sustainable Development Goals (SDGs) demonstrates that there is a definite connection between environmentally responsible forestry practices and India's overall success in achieving all of the SDGs. The forest resources and associated industries in India contribute in a myriad of ways to the advancement of sustainable development. Not only does it play a part in the protection of the natural environment, but it also contributes in the areas of economics, society, and institutions. By providing natural resources and means of subsistence to underserved populations, sustainable forestry has a direct bearing on the achievement of SDG 1, which is the elimination of global poverty. It does this through preserving forest-based livelihoods, environmental services, and biodiversity, all of which contribute to the achievement of SDG 2: food security (Di Gregorio et al., 2019). It does this by providing clean air and medical supplies and controlling disease vectors, all of which contribute to health and well-being (SDG 3).

To accomplish the goal of achieving gender equality (SDG 5), it is vital to implement forest management practices that include the active involvement of women. As natural water filters, forests contribute to the achievement of Sustainable Development Goal 6 (clean water and sanitation). In addition, the transition away from firewood and towards cleaner fuels as part of government-sponsored programs helps to the achievement of the Sustainable Development Goal 7 (SDG 7). Productivity may be increased by the use of modern technology in forest management, which in turn promotes decent labor and economic expansion (SDG 8). In the framework of innovation and infrastructure (SDG 9), sustainable forestry contributes by using cutting-edge technology such as geographic information systems (GIS), the internet of Things (IoT), and artificial intelligence (AI) (Lu et al., 2016). Through the engagement of local people in conservation efforts, forestry programs also contribute to the achievement of Sustainable Development Goal 10, which aims to eliminate inequality.

The establishment of green space and urban forestry are both important parts of the endeavor to make cities and communities more sustainable (SDG 11). Meanwhile, education on the responsible use of forests has an impact on responsible consumption and production (SDG 12) (Rasul, 2014). Carbon sequestration is another important way that sustainable forestry may help achieve Sustainable Development Goal 13 (to combat climate change). Sustainable forestry helps the preservation of mangrove forests and other coastal ecosystems, which is a goal of Sustainable Development Goal 14 (SDG 14) mainly because protecting life on land is one of the Sustainable Development Goals (SDG 15), which is at the core of sustainable forestry (Tang and Shao, 2015; Doimo, Masiero, and Gatto, 2020). Sustainable forestry projects in India play a significant part in dispute resolution and the acknowledgement of forest rights, which are all important aspects of SDG 16, which focuses on promoting peace, justice, and strong institutions. Last but not least, the successful completion of these objectives cannot be accomplished without strong collaborations (SDG 17), which are also encouraged by the forestry industry (Lowman, Schowalter and Franklin, 2019; Shi et al., 2020). Therefore, sustainable forestry is not just about trees; it is closely intertwined with practically all areas of sustainable development, which makes it an important component in India's attempts to attain the Sustainable Development Goals (SDGs). The research offers significant policy-making implications and suggests future areas of study in technological integration and balancing economic and environmental goals in natural resource management.

- Summary and Main Contribution to Chapter 6: Assessment of criteria and indicator system for sustainable forest management: A case study of Madhya Pradesh

The final research question was, "The criteria and indicator system for sustainable forest management in India can help in the policy decision-making process?" The analysis conducted using the fuzzy Analytic Hierarchy Process (AHP) to evaluate the factors affecting sustainable forest management in India reveals a compelling prioritization of environmental considerations over social and economic factors. This prioritization underscores the critical importance attributed to ecological integrity and ecosystem services in the management of Indian forests. The findings, which emerge from a comprehensive assessment of three main criteria and thirteen sub-criteria, offer a nuanced understanding of sustainable forest management that significantly leans towards environmental sustainability.

The Environmental criterion, with a global weight of 1, emerges as the paramount concern, reflecting an acute awareness of the indispensable role forests play in maintaining ecological balance, regulating climate, enhancing biodiversity, enriching soil, purifying air, and acting as CO2 sinks. This emphasis is well-supported by the literature, with various studies (Rai et al., 2012; Amarnath, Babar & Murthy, 2017; Kumar et al., 2021) highlighting the criticality of environmental factors in forest management within the Indian context. Such a focus is indicative of a strategic orientation towards leveraging forest management as a tool for addressing broader environmental challenges, including climate change and biodiversity conservation.

Conversely, the Social and Economic criteria, both assigned a global weight of 0, are deemed to have negligible impact on sustainable forest management decisions relative to environmental concerns. This does not diminish the importance of forests in providing livelihoods and economic benefits but indicates a strategic decision to prioritize ecological considerations at the potential expense of immediate social and economic benefits. This finding resonates with Yadav & Dugaya (2013) and Saigal et al. (2013), who acknowledge the socio-economic contributions of forests but suggest that these are currently secondary to environmental sustainability goals in policy formulation and implementation.

The detailed analysis of sub-criteria further illustrates the specific areas of focus within each main criterion. The significant weight given to 'Employment' under both Social and Economic criteria highlights the recognition of forestry as a vital source of livelihood despite the overall lower prioritization of these criteria. Meanwhile, the Environmental sub-criteria emphasize the multifaceted roles forests play in ecological processes and climate regulation, aligning with global sustainability objectives and the urgent need for environmental conservation highlighted in the literature (Datta and Chatterjee, 2012; Chattopadhyay & Datta, 2010; Dwivedi et al., 2009).

7.2 Recommendations

The act of restoring forest ecosystems that have been degraded has been shown to enhance the health of forests and increase their resilience to the impacts of climate change, as evidenced by studies conducted by Buchholz et al. (2016), Beland et al. (2019), and Anderegg et al. (2015). Through the augmentation of tree coverage, these endeavours have the potential to amplify carbon sequestration, govern regional climate, and preserve biodiversity. The Bonn Challenge has set a target of rehabilitating 350 million hectares of degraded forests and deforested lands by the year 2030, which has the potential to sequester approximately 1.7 gigatonnes of carbon dioxide on an annual basis, as stated by Mackey et al. (2020).

The translocation of tree species to new locations with anticipated suitable climate conditions, known as assisted migration, could serve as a potential strategy in response to the impact of climate change on the habitats of various tree species (Schulz et al., 2016; Garcia et al., 2014; Wagner et al., 2014). Nevertheless, the implementation of this approach necessitates meticulous assessment of its potential effects on the recipient ecosystems to prevent inadvertent outcomes such as the proliferation of invasive species or the disturbance of indigenous ecological mechanisms (Laube et al., 2013).

The implementation of modified forest management techniques, known as adaptive forest management, entails the modification of silvicultural practises in reaction to both anticipated and observed shifts in climatic conditions. The implementation of certain techniques such as mixedspecies planting, selective cutting, and preservation of mature forests, which have demonstrated greater resilience to climate-induced disruptions, have been suggested as potential solutions (Neumann et al., 2017; Beland et al., 2019; Anderegg et al., 2015). According to Domke et al. (2020), the implementation of adaptive measures can aid in preserving forest productivity and carbon sequestration, while simultaneously mitigating the susceptibility to disturbances such as pest outbreaks or wildfires.

It is imperative to take into account the regional contexts and potential trade-offs when considering the utilisation of adaptive strategies to alleviate the effects of climate change on forest ecosystems. It is important to note that certain strategies may not be suitable or efficacious in every circumstance, and their successful execution necessitates a thorough comprehension and evaluation of the ecological, social, and economic factors specific to the locality (Garcia et al., 2014; Wagner et al., 2014; Sandel et al., 2011; Fuentes-Castillo, T., Hernández & Pliscoff, 2020). It is imperative that these tactics are complemented by comprehensive endeavours to curtail the emission of greenhouse gases and decelerate the rate of climate change.

The phenomenon of climate change has notable repercussions on forest ecosystems, which manifest in alterations to their composition, operation, and the essential services they furnish to the environment. Forests are confronted with several significant challenges in the context of global climate change, including alterations in temperature and precipitation patterns, shifts in phenology and species distribution, loss of biodiversity, heightened forest disturbances, and changes in the capacity for carbon sequestration. The implementation of adaptive strategies and management responses, such as forest restoration, assisted migration of tree species, modified forest management practises, and genetic diversity enhancement, are effective measures to alleviate the effects of climate change on forests and enhance their resilience. The efficacy and suitability of these approaches will be contingent upon the context and necessitate a thorough comprehension and evaluation of regional ecological, social, and economic considerations.

The integration of ecological science, social science, and local and indigenous knowledge through a transdisciplinary approach is essential for effectively tackling multifaceted challenges. In order to ensure the preservation and durability of our forest ecosystems amidst the challenges posed by climate change, a collaborative endeavour must be undertaken across all strata of society, ranging from grassroots communities to global institutions. In order to achieve this objective, it is imperative to amalgamate the processes of policy formulation, empirical investigation, and pragmatic implementation. The preservation of forests is of utmost importance to maintain worldwide biodiversity, regulate climate, and enhance human welfare. Thus, it should be considered a fundamental element in our endeavours to construct a durable and adaptable future.

7.3 Challenges

Despite the considerable progress made in the field of sustainability, numerous challenges remain, and identifying future directions is crucial to overcoming them. One of the most significant challenges is the complexity and interconnectedness of sustainability issues (Boström, 2012). The interconnectivity of environmental, economic, and social systems implies that modifications in one domain may yield unanticipated outcomes in another (Köhler et al., 2019). Addressing these complexities requires a transdisciplinary approach, where multiple disciplines work collaboratively to produce holistic and integrated solutions.

Another challenge is the implementation gap. While sustainability principles have been widely recognized and adopted in policy and planning, their translation into practice is often inconsistent and inadequate (Xie et al., 2016). Bridging this gap necessitates developing effective implementation strategies, improving monitoring and evaluation mechanisms, and strengthening governance and institutional capacities. Additionally, the issue of equity and justice is central to sustainability. However, inequalities persist both within and between countries, and many sustainability initiatives have inadvertently exacerbated social disparities (Foong et al., 2020). Therefore, future sustainability efforts must prioritize equity and inclusivity to ensure that benefits are shared broadly and that no one is left behind (Latapí Agudelo, Jóhannsdóttir & Davídsdóttir, 2019).

Looking forward, a major direction for sustainability is the shift towards systemic change. Recognizing that piecemeal and incremental approaches are insufficient, there is a growing call for transformative changes that fundamentally alter the structures and systems underlying unsustainable practices. In the realm of economics, a potential course of action could involve transitioning from a linear economic model to a circular one, or shifting from a growth-focused economy to a well-being or steady-state economy. In the social domain, it could involve strengthening social capital and community resilience, fostering social innovation, and promoting cultural shifts towards sustainability (Boström, 2012).

Ultimately, addressing the challenges of sustainability and moving towards these future directions will require ongoing research, dialogue, and action. It will necessitate a collaborative effort involving governments, businesses, academia, civil society, and individuals, with a shared commitment to a sustainable and equitable future.

7.4 Future Directions for Sustainable Development Goals

The Sustainable Development Goals (SDGs) encounter various obstacles in their path, such as enduring inequality, swift urbanisation, climate change, and the recent disturbance brought about by the worldwide pandemic. Nonetheless, these challenges also offer prospects for reevaluating and enhancing the approaches to accomplish the Sustainable Development Goals (SDGs) as stated by Costanza et al. (2016). Griggs et al. (2013) suggest that a potential avenue for future research is to more explicitly consider the interlinkages between the Sustainable Development Goals (SDGs). Although the 17 Sustainable Development Goals (SDGs) are inherently interrelated, ongoing endeavours frequently tackle them individually. The identification and utilisation of synergies between objectives can potentially augment their efficacy. Investments in renewable energy, as exemplified by SDG 7, have been shown to have multiple benefits, including the mitigation of climate change (SDG 13), the creation of job opportunities (SDG 8), and the promotion of health through the reduction of air pollution (SDG 3), as demonstrated by Lu et al. (2015). Incorporating the Sustainable Development Goals (SDGs) into all policy and planning procedures is deemed a pivotal course of action, as highlighted by Fukuda-Parr et al. (2016). The process entails the incorporation of the Sustainable Development Goals (SDGs) into both national development strategies and corporate strategies and practises. The implementation of sustainable consumption and production patterns is a crucial component of this strategy, necessitating a fundamental transition towards circular economies (Wu et al., 2018).

Enhancing international collaboration is of utmost importance, considering the worldwide scope of the Sustainable Development Goals (SDGs). This entails the establishment of efficient collaborations and the activation of funds, specifically for nations in the process of development. It is imperative to involve all stakeholders, such as civil society, academia, the private sector, and marginalized groups, in the decision-making processes to ensure effective governance (Gupta & Vegelin, 2016).

The acquisition of comprehensive and differentiated data to oversee advancements and facilitate policy-making is an additional crucial domain (Kumar Kumar & Vivekadhish, 2016). According to Biermann, Kanie, and Kim (2017), the utilization of emerging technologies, such as big data and artificial intelligence, can significantly contribute to the provision of more precise and prompt data for tracking the progress of Sustainable Development Goals (SDGs).

The evolution of sustainability over time and the emergence of the Sustainable Development Goals (SDGs) reflect the shared determination of the international community to establish a harmonious relationship between human progress and environmental conservation. The evolution of sustainable practises can be traced back to the early environmental movements, which played a pivotal role in raising awareness about the health of our planet. The Brundtland Commission's definition of "sustainable development" further contributed to this evolution. Finally, the establishment of the SDGs marked a significant milestone in our understanding and implementation of sustainable practises.

The Sustainable Development Goals (SDGs) offer a comprehensive and interconnected framework that serves as a guide for global development endeavours until the year 2030. Although the SDGs propose an ambitious agenda for promoting sustainability and inclusivity on a global scale, their execution and outcomes have yielded a varied range of results. Although notable progress has been made in specific domains, significant obstacles remain that the international community must confront. The COVID-19 pandemic has highlighted the susceptibilities of our societies and economies, emphasising the necessity for development that is both resilient and sustainable while also being inclusive.

In the context of the Decade of Action aimed at achieving the Sustainable Development Goals (SDGs) by 2030, the prospects for sustainable development entail capitalizing on the interconnections among the SDGs, incorporating them into all policy and planning procedures, reinforcing global partnerships and multi-stakeholder strategies, and exploiting emerging technologies for data and monitoring purposes.

Future Research direction for the author includes the following

-Participatory Framework Validation: Conduct multi-stakeholder workshops across different forest regions in India to validate and refine the ASLF components.

-Cross-Sectoral Policy Analysis: Examine institutional arrangements, governance models and coordination mechanisms needed for effective SDG-forest integration.

-Empirical Case Studies: Conduct more empirical case studies to specific forest management contexts to test its practical utility and identify implementation challenges.

-Participatory Action Research: Engage forest communities in co-creating locally adapted versions of the framework that reflect traditional ecological knowledge and community priorities (especially focusing on scope of gender equality and its influence in sustainable forest management).

Summary and main contribution of the chapter

The notion of sustainability, although formally established only recently, has historical antecedents that can be traced back to the nascent environmental movements of the past. Sustainability has undergone a transformation from its initial stages to a comprehensive strategy that strives to achieve equilibrium among economic, social, and environmental considerations. The advancement in sustainability principles has been demonstrated through the integration of corporate social responsibility, the implementation of the Sustainable Development Goals, and the emergence of contemporary trends such as circular economies and sustainable cities.

Notwithstanding the progress made in the field of sustainability, it is confronted with a number of obstacles such as the intricate nature of interrelated concerns, the disparity between policy formulation and execution, and the enduring presence of societal inequities. The aforementioned challenges serve as evidence that sustainability is not a fixed objective, but rather a constantly evolving procedure that necessitates ongoing adjustment and enhancement. Additionally, they highlight the necessity of implementing systemic and transformative modifications, while emphasizing the significance of giving priority to equity and inclusivity in endeavors towards sustainability.

Prospectively, sustainability will persist as a pivotal guiding doctrine for individuals, entities, and communities globally. Achieving sustainability and equity in the future will necessitate sustained endeavors from all societal sectors, underpinned by a collective dedication to this goal. Through this approach, it is possible to guarantee the responsible, equitable, and efficient utilization of the planet's resources, thereby fostering a healthy, prosperous, and resilient world for both current and future generations.

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