Mehebub Sahana
Gopala Areendran
Krishna Raj *Editors*

Conservation, Management and Monitoring of Forest Resources in India

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Foreword

It is a great pleasure to pen the Foreword to the book *Conservation, Management and Monitoring of Forest Resources in India* edited by Dr. Mehebub Sahana, Dr. Gopala Areendran, and Dr. Krishna Raj from WWF-India. Forests are not only a source of timber but they also provide rich biodiversity, food and water, and economic opportunity, foster a culture, generate significant non-wood goods and services, mitigate climate change, conserve biological diversity, provide protection from natural hazards, and support people's livelihoods. Thus, the topic of this book is very relevant to the present era of global climate change with impending threats of multi-hazard events. This book has covered several contemporary important themes ranging from forestry, wildlife, habitat fragmentation, conservation biology, forest ecology, forest management to the use of GIS in forest science, and human wildlife conflict research.

This book has been very effectively organized into five thematic parts: Part I covers the Forest Conservation Ecology, Part II represents Forest Conservation and Society, Part III talks about Forest Management, Part IV illustrates Forest Monitoring Using GIS and Remote Sensing, and Part V deals with Human-Wildlife Conflicts. These 20 research papers encompass in-depth scientific analysis of forest conservation, management, human-wildlife conflict, and various socio-economic perspectives of forest resources. Each chapter provides a review of the current understanding of knowledge exploiting the scope of present research and offering possibilities and direction for future efforts. The chapters are arranged by the editors in an orderly sequence leading to a comprehensive and complete understanding of the topic concerned.

Therefore, I hope this book will be very helpful to researchers, scientific organizations, wildlife scientists, biologists, ecologists, and planners in the field of wildlife and forestry. I congratulate the authors for this unique contribution, and I hope that the volume will be well accepted by its serious readers, intended to be research scholars, faculty members of higher education institutions, and scientists of different organizations across countries. I wish all the very best for its wide circulation and admiration. I extend my warmest greetings to the editors, authors, and all those associated with the publications of this book and wish that the book will gain a wide readership. I congratulate Springer Nature for launching this book.

World Resources Institute India,
New Delhi, India
Parth Sarathi Roy

Foreword

Forest resources in India have always remained at the center of several development issues—including environmental stability and ecological security. At the same time, forests continue to provide a wide range of goods and services to society and economy. In addition to these, forests play a significant role in the existence of a wide range of lifeforms including human beings, many more resources than one can think, and overall well-being of the planet that concerns sustainability and climate change-related challenges. Thus, forests remain a topic of public interest and political strategies from local to global scales while having relevance for past, present, and future decisions.

The book *Conservation, Management and Monitoring of Forest Resources in India* provides a collection of chapters that are excellent examples of advanced works applied to relevant problems central to forest resources in India and is of interest to the global community. This book covers key areas in forest monitoring, management, conservation ecology, society, and human-wildlife conflicts while using GIS and remote sensing. The compendium will be a valuable resource to scholars interested in conservation education and practices, landscape level monitoring and planning, wildlife management along with forest resource monitoring and conservation. The book provides an overview of the issues, challenges, and opportunities related to these subthemes of forest resources.

The rapid progress in forest resources studies and the numerous researches conducted under the auspices of forests monitoring, conservation, and management, in both India and other countries, often render it a difficult task to interpret facts which keep accumulating on a daily basis. This book provides a valuable window on the essentials and covers the necessary components of forest monitoring and management relevant to all stakeholders who care for forests and wish to learn more about it. The editors with their decades of distilled experience of knowing and working in different forest ecosystems of India have taken a range of geographies, respective challenges, and solutions thereon while preparing this compendium.

I congratulate the entire team of editors for such a thoughtful and valuable addition to the existing body of knowledge, which was much needed for a serious readership. This is especially intended for university teachers, students and researchers, professionals working in technical and nontechnical institutions, and decision makers and policy makers to provide a wider coverage on the facets of forest resources and ecology. This stands as a good textbook in addition to being a reference material. Readers of the book will find it to be a useful learning tool and a valuable reference in their further career in forestry, ecology, and geography.

School of Environmental Sciences, P. K. Joshi
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2021

Preface

Forests are vital for all life on earth. Forests provide rich biodiversity, food and water, economic opportunity through timber, foster a culture, and support people's livelihoods. Recently, the role of forests in terms of climate change mitigation and adaptation has been increasingly gaining attention worldwide as deforestation and forest degradation account for more than 10 percent of total CO_2 emissions. While everyone affirms the importance of forests, there was a 129-million-hectare forest net loss between 1990 and 2015. The loss of tropical forests continues unabated due to agricultural expansion, wood extraction, infrastructure expansion, illegal logging, and other factors, making it high on the global political agenda to address those drivers in order to stop such losses. Climate change continues to be a top threat facing the forests of India, especially in the Himalayan region. Thus, conservation and monitoring of forest resources is an essential task. Indira Gandhi Conservation Monitoring Centre (IGCMC) at WWF-India has been working on conservation and monitoring of forest resources for the last 25 years with several collaborations all over the world. To improve the interest and understanding of contemporary young researchers, the idea of conservation should be promoted globally. With this essence, a book needs to be compiled, devoted to putting together a collection of the recent advancements, methodological improvements, new processing techniques, integration methods, and rigorous applications combined with conceptual techniques on the conservation topic at a single place for the scientific audience.

The primary objective of this book is to advance the scientific understanding of the recent trends of forest conservation, management, and technological improvements and related research themes on forest resource and wildlife in India. This book has covered several themes related to forestry, wildlife, habitat fragmentation, forest management, and human wildlife conflict research. Therefore, researchers, scientific organizations, wildlife scientists, biologists, ecologists, and planners in the field of wildlife and forestry will benefit from this book. The journey of this book started with the invitation of academician, wildlife scientists, biologists, ecologists, and planners all over India to contribute to *Conservation, Management, and Monitoring of Forest Resources in India* in September 2019. We received huge response from

several authors from multidisciplinary subjects related to forest research. Hence, we are very much thankful to authors who contributed to this volume. Their thoughtful contributions made this volume possible. We acknowledge our debt to Springer International Publishing, especially to Aaron Schiller the responsible editor of *Earth Sciences, Geography and Environment* for associating with us and providing their valuable suggestions and guidelines. We express our sincere appreciation and gratitude to the Secretary General and CEO, Mr. Ravi Singh for the vision he laid out for our work. We are also thankful to our Program Director, Dr. Sejal Worah, who was always there to guide us whenever required and provided all the organizational support.

Manchester, UK
New Delhi, India
January, 2022

Mehebub Sahana
Gopala Areendran
Krishna Raj

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About the Editors

Mehebub Sahana is a cultural and environmental geographer with an interest in analyzing land-use changes with special respect to spaces, politics, and the governance of the living and materialistic world. His present research interests include social–environmental interface, socio-ecological resilience, and systems thinking; complexity thinking and systems analysis; geohazards; landscape ecology; multi-hazard risk assessment; land-use change; rural–urban conversion and the socio-political implications of land-use dynamics. He is currently working as a Research Associate at the School of Environment, Education and Development, The University of Manchester, UK. Previously, he was employed as a Contractual Lecturer in Geographical Information Systems (2018–2019) at Indira Gandhi Conservation Monitoring Centre (IGCMC), WWF-India, New Delhi. He was a GIS Research Assistant (2013–2016) in the DIGITAL ATLAS Project at Jawaharlal Nehru University, New Delhi, India. He received his Ph.D. in Environmental Geography (2018) from Jamia Millia Islamia University, New Delhi, India. He has contributed more than 35 scientific research papers to international journals on issues pertaining to land-use changes and environmental degradation and their links with climate change-induced vulnerabilities.

Gopala Areendran is the Director of IGCMC at WWF-India. He has more than 25 years of experience as a professional and leader in geospatial technology and has been the driving force of location-based data monitoring and analytics since 2001 at WWF-India. His work at WWF ranges from addressing conservation issues occurring in various landscapes, with a high focus on tiger, elephant, and rhinoceros to overseeing several institutional GIS-based projects. Dr Areendran has an MS degree in Ecology from Pondicherry University and PhD from Wildlife Institute of India. He has also worked with leading research centers like Salim Ali Centre for Ornithology and Natural History (SACON); Wildlife Institute of India (WII); Madras Environmental Society (MES), Chennai; and the Institute of Remote Sensing, Anna University, Chennai. He has published several research papers and reports in peer-reviewed journals and was involved in publication of four books in the capacity of editor and coauthor. As a pioneer of geospatial education, he has also supervised over a hundred masters and research students.

Krishna Raj a Specialist in Geospatial Application, has done Masters in Geography from Banaras Hindu University, Varanasi, India, and PG Diploma in Advanced Remote Sensing and Cartography. Presently working with WWF-India as Sr. Program Coordinator (GIS/RS), IGCMC, WWF-India, and responsible for all kinds of GIS and remote sensing projects within IGCMC, WWF-India. He has handled Geospatial Modeling and Analytical work in various major research projects of WWF-India for the last 20 years. Prior to joining WWF-India, he has worked with multinational company RMSI as a GIS Engineer and in Lepton Software India Ltd. as GIS Professional and got expertise in different Remote Sensing and GIS projects.

Part I
Forest Conservation Ecology

Chapter 1
Introduction to Forest Resources in India: Conservation, Management and Monitoring Perspectives

Mehebub Sahana, G. Areendran, Krishna Raj, Akhil Sivadas, C. S. Abhijitha, and Kumar Ranjan

Abstract India is known to have a vivid array of forests from the rainforests in Kerala to the alpine pastures in Ladakh and the desert pastures in Rajasthan to the evergreen forests situated in the north-east. Numerous parameters determine the type of forest such as climate, soil type, elevation and topography. Forests are categorized into diverse types based on the type of climate in which they are found, their nature and composition and their relationship with the surrounding environment. According to ISFR (2019), the total forest and tree cover of the country accounts for about 24.56% of the geographical area, which is 80.73 million hectares. 99,278 sq.km is covered by very dense forest, 3, 08,472 sq.km area is covered by moderately dense forest and 3,04,499 sq.km area is covered by open forest. According to the assessment in ISFR 2019, there was an observed upsurge of 5188 sq.km in the area covered by forest and tree cover combined, at the national level, as compared to the assessment carried out earlier in 2017. There was an upsurge in the area covered by overall forest and tree cover at the national level, but there was a decrease in the forest area in the country's north-east region as emphasized in the report. It was also observed that Arunachal Pradesh had maximum species richness in terms of trees, shrubs and herbs followed by Tamil Nadu and Karnataka. Champion and Seth (A revised survey of the forest types of India. Govt. of India Publication, New Delhi, 1968) have used temperature and rainfall data for the classification of Indian forests into five major forest types and 16 minor forest types and more than 200 subgroups. In India, the major forest type groups are tropical semi-evergreen, tropical moist deciduous, littoral and swamp, tropical dry deciduous, tropical thorn, sub-tropical broad-leaved hill forests, sub-tropical dry evergreen, Himalayan moist and dry temperate, sub-alpine, montane wet temperate

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moist alpine scrub and dry alpine scrub. The tropical moist littoral and swamp forests of Sundarbans are constituted by mangroves. Mangroves are salt-tolerant plant communities that inhabit tropical and sub-tropical intertidal regions of the world and have developed into a good habitat for tigers. Though the diversity of forest resources in India is remarkable, the status of deterioration of these resources should also be monitored. The primary causing serious threats include loss of forest cover due to shifting cultivation, illegal felling, conversion of forest lands for urban expansion and other biotic pressures. Illegitimate cutting of trees has impacted the climatic conditions at a micro-level. It has affected the soil quality, hydrological cycle and biodiversity of the country, thus making the country more exposed to natural calamities and climate change. Most forests are under threat due to strong anthropogenic pressure, extensively due to collection of fuel wood and livestock grazing. Effective management strategies that take into account restoration and also promote judicious use of forest resources would ensure sustainability in the long run.

Keywords Forest resources · Forest loss · Conservation · Forest types · Mangroves

1.1 Introduction

A forest is referred to as an area with a thick tree canopy (Pawar and Rothkar 2015). Forests could be classified as according to size and are classified according to how and what the forest is comprised of (Pawar and Rothkar 2015). Forests cover a land area of approximately 9.4% of the surface of the Earth and approximately thirty percent of the entire land area. Earlier, the area covered by forests was much more than 30% (Pawar and Rothkar 2015). They perform diverse functions that help in sustaining the overall balance of the ecosystem. They provide services such as:

- Maintain different biogeochemical cycles
- Act as conservators of soil habitat
- Provide habitat for various species

and constitute one of the most primary aspects of the biosphere (Pawar and Rothkar 2015). The world's forests not only are responsible for providing an important habitat for all species but also uphold the overall health of the planet (Sahana et al., 2015; Agar 2019). The paybacks of forests to society and to the diversity of life make it necessary that they have to be protected from detrimental impacts of deforestation and other impending negative influences of civilization (Sahana et al., 2018; Agar 2019). Forests provide many ecosystem services which are classified as provisioning, supporting, cultural and regulating.

1.1.1 Ecological Role of Forests

Forests are primary contributors to the earth's capability to maintain its climate, through the global impact of photosynthesis (Agar 2019). They act as natural protectors against climate change by eliminating greenhouse gases and generates oxygen, which eventually assists in cleansing the atmosphere and controlling rising temperatures (Agar 2019). Forests act as modulators of water circulation, and trees facilitate a shielding cover that keep a check on the impact of rainfall on soil, and hence soil erosion is minimized (ENVIS Centre-Maharashtra n.d.). Soil is affixed firmly at its position with the help of roots, and the canopy provides shade that prevents the soil from becoming too dry, which in turn increases the soil's moisture holding capacity (ENVIS Centre-Maharashtra n.d.). Forests assist in air purification by cooling the atmosphere on warm days, help preserve heat at night and absorb sound efficiently (ENVIS Centre-Maharashtra n.d.). Transpiration from a forest has a significant impact on the relative humidity and precipitation of a particular area (ENVIS Centre-Maharashtra n.d.). Forests also help in cleansing the environment by dampening noises, buffering strong winds and averting dust and gases (ENVIS Centre-Maharashtra n.d.). The thick forest floor created by a multitude of leaf layers that avoids runoff and allows water to penetrate into the soil which facilitates groundwater recharge (ENVIS Centre-Maharashtra n.d.). Forest cover plays a significant role in regulating the amount of precipitation received by an area and hence maintains the water cycle of the area (ENVIS Centre-Maharashtra n.d.). Some tree species use root decomposition as a mechanism to return atmospheric nitrogen to the soil and hence increase the nitrogen content of the soil (ENVIS Centre-Maharashtra n.d.). The health of watersheds is always maintained as forests help in keeping a check (ENVIS Centre-Maharashtra n.d.). Rivers that originate from a forested area usually bring along the organic matter of that area downstream and sustain different varieties of fishes and other aquatic organisms (ENVIS Centre-Maharashtra n.d.). The abundance and diversity of the forest upstream are parameters that decide whether the river ecosystem supported by it has a significant biological value (ENVIS Centre-Maharashtra n.d.). Forests play a crucial role in carbon sequestration by capturing carbon dioxide and transformation of it into biomass through photosynthesis (Babbar et al., 2021; UNECE n.d.). Sequestered carbon is then stored in the form of biomass, deadwood and litter in the soil of the forest (UNECE n.d.).

1.1.2 Economic Role of Forests

Forests are important sources of fuel wood and various NTFPs (Non-Timber Forest Products) like medicinal plants, bamboo, cane, food, spices, fibres, essential oils, ritha and shikakai, and tendu leaves which not only sustains local livelihoods but also boosts the economy of the country (ENVIS Centre-Maharashtra n.d.). The lives of cattle and other grazing animals are sustained by fodder provided by forests; in addition to this, forests are also placing of aesthetic value and promote recreational activities (ENVIS Centre-Maharashtra n.d.). The social importance of NTFPs are not necessarily accounted by the economic value per hectare of forests because the benefits of NTFPs are attributed mainly to local communities who are dependent on forest resources for their sustenance (Pearce 2001).

Deforestation can be defined as the removal or destruction of vast areas of forests for various reasons, like logging, agriculture, natural disasters, urbanization and mining (Pokhriyal et al., 2020; Pawar and Rothkar 2015). The abrupt impact of deforestation arises at the regional level which is marked by the loss of ecosystem services provided by tropical rainforests and other ecosystems like reduction in the availability of renewable resources (Butler 2019). With loss in the forest cover of a particular area, the local community loses the system that executed valuable but often under-appreciated services like facilitating the regular flow of clean water and protecting the community from natural disasters (Butler 2019). When forests are damaged, moisture which is evapo-transpired into the atmosphere decreases, causing formation of less clouds that consequently leads to decline in rainfall, eventually causing drought (Butler 2019). Widespread deforestation leads to desiccation, thus reducing the moisture content of the forests which could cause forest fires (Butler 2019). Heavy rainfall on cleared forest lands creates run-off that transports soil into local creeks and rivers which then carry the eroded soils downstream, thus causing significant damage (Butler 2019). Siltation raises river beds, aggregating the severity of floods, and creates shoals and sandbars that make navigation through rivers far more troublesome, and the increased sedimentation of rivers smoothens fish eggs, triggering lower hatch rates (Butler 2019).

Forests are being deteriorated for a very long time; therefore, efforts to stop or slow down the rate of deforestation are important as it causes serious environmental impairment (Pawar and Rothkar 2015). It is of utmost importance that we gain enough knowledge about various environmental aspects of forests and deforestation to ensure that the world is a better place to live in and that biodiversity is preserved as well (Pawar and Rothkar 2015).

1.1.3 Forest Types in India

Forests can be classified based on different parameters such as climate and soil characteristics of an area that come under abiotic factors (ENVIS Centre-Maharashtra n.d.). Indian forests can be widely classified into broadleaved and coniferous forests (ENVIS Centre-Maharashtra n.d.). Deciduous, mangroves and evergreen forests are forests that are categorized based on the nature of tree species (ENVIS Centre-Maharashtra n.d.). Sal or teak forests are considered to be one of the most abundant types also, which shows that forests can be classified based on the abundance of trees found in a specific region (ENVIS Centre-Maharashtra n.d.). The forests in that region are then known by three or four tree species that occur abundantly in that specific region (ENVIS Centre-Maharashtra n.d.).

Coniferous forests are those that grow in the Himalayan region at relatively low temperature (ENVIS Centre-Maharashtra n.d.). These forests are characterized by the presence of stately trees that are tall and have leaves that are inclined branches that are inclined downward for the snow to slide down along them (ENVIS Centre-Maharashtra n.d.). Deciduous forests, thorn forests, evergreen forests and mangrove forests are broad leaved forests. They have leaves that are generally of large size and of different shapes and are found between latitude ranges from low to middle (ENVIS Centre-Maharashtra n.d.). Northeast India, Western Ghats and Andaman and Nicobar Islands have evergreen forests that receive high rainfall and where the monsoon continues for several months (ENVIS Centre-Maharashtra n.d.). Deciduous forests grow in areas that receive reasonable amount of rainfall that is seasonal and remains for a few months (ENVIS Centre-Maharashtra n.d.). These forests mainly comprise of teak trees that shed their leaves during the winters and hot summers (ENVIS Centre-Maharashtra n.d.). Thorn forests are sparsely distributed and found in the semi-arid areas of India, mainly surrounded by open grasslands (ENVIS Centre-Maharashtra n.d.). Mangrove forests are found along coastal areas, especially in the river deltas where there is a mixture of saline and freshwater (ENVIS Centre-Maharashtra n.d.). They are found profusely in areas that are muddy and covered with silt that the rivers have carried downstream (ENVIS Centre-Maharashtra n.d.). Mangroves possess breathing roots that rise from the muddy river banks and are highly adaptable to estuarine ecosystems (ENVIS Centre-Maharashtra n.d.). Champion and Seth (1968) classified Indian forests into six groups, namely, dry tropical forests, montane sub-tropical forests, moist tropical forests, montane temperate forests, sub-alpine forests and alpine forests.

1.1.4 Moist Tropical Forests

Tropical wet evergreen forests have 30–45 m four- or five-layered canopy and usually occur in areas that receive precipitation ranging from 2000 to >3000 mm per year and are dense forests (Gupta n.d.). The tree species diversity in these forests is considered to be rich (Gupta n.d.). The forests are intermittently scattered mostly along the north-eastern part of India, Western Ghat region and Andaman and Nicobar Islands (Gupta n.d.). It is further divided into northern and southern wet tropical evergreen forests (Gupta n.d.). Southern tropical wet evergreen forests are found in Western Ghats range, Andaman and Nicobar Islands and the commonly distributed genus in them include *Dipterocarpus* and *Hopea* (Gupta n.d.). Rainfall ranges from 1500 to 5000 mm in the Western Ghats, and altitude varies from 250 to 1200 m (Gupta n.d.). On the other hand, the northern wet tropical forests are found in higher regions of Assam, northern Arunachal Pradesh and West Bengal (Gupta n.d.). They are mainly dominated by trees that belong to the Dipterocarpaceae family (Gupta n.d.). Bamboos are generally found in these areas (Gupta n.d.). Climbers are plentiful, and palms and canes are also commonly found; there is rich diversity of epiphytes, and ground cover is predominantly composed of evergreen shrubs (Gupta n.d.). Tropical semi-evergreen forests are found in areas adjoining tropical wet evergreen vegetation and form a transition zone between evergreen and moist deciduous forests (Gupta n.d.). They may attain 40 m height and receive rainfall of 2000–2500 mm and thrive in temperature of 25–32 °C, usually dominated by *Magnolia*, *Cinnamomum*, *Terminalia*, *Xylia*, etc. (Singh and Chaturvedi 2017).

They are further divided into southern tropical semi-evergreen forest and northern tropical semi-evergreen forest. Tropical moist deciduous forests are commonly found in areas with rainfall that ranges between 1000 and 2000 mm and experience a dry season for approximately 3 to 4 months (Gupta n.d.). Deciduous trees are dominant, typically evergreen in the lower portions, and their leaves are shed during colder months (Gupta n.d.). This type of forest is extensively distributed in Tamil Nadu, Arunachal Pradesh, West Bengal, Assam, Meghalaya, Mizoram, Bihar, Odisha and Uttarakhand (Gupta n.d.). They are further divided into southern moist deciduous forests and moist deciduous forests. Littoral and swamp forests are principally evergreen and consist of mangrove and freshwater swamp forests dominated by *Rhizophora*, *Bruguiera*, *Ipomea*, *Phoenix*, *Barringtonia*, etc. (Gupta n.d.).

1.1.5 Dry Tropical Forest

Tropical dry deciduous forests occur in regions that display seasonality in rainfall and experience persistent drought period annually (Gupta n.d.). They comprise of trees that grow less than 25 m high and develop a canopy that is light demanding (Gupta n.d.). These forests are distributed along Kanyakumari to the hills of Himalayas that receive less rainfall ranging from 800 to 1200 mm (Gupta n.d.). These forests act as favourable wildlife habitats (Gupta n.d.). Southern and northern regions have dry teak and sal forest communities (Gupta n.d.). In some areas, a mixture of tree species like *Anogeissus pendula*, *Boswellia serrata*, *Hardwickia binata*, *Acacia nilotica*, *Madhuca indica* and *Butea monosperma* are found (Gupta n.d.). They are divided into two forest types, namely, Southern tropical dry deciduous forest and northern tropical dry deciduous forest. Southern tropical dry deciduous forests are spread across Maharashtra, Karnataka, Andhra Pradesh, Madhya Pradesh and Tamil Nadu (Gupta n.d.). Northern tropical dry deciduous forests are present in Bihar, Bengal, Odisha, Gujarat, Uttar Pradesh and Haryana (Gupta n.d.). Tropical thorn forests are mainly deciduous forests having low thorny trees. They thrive in areas which receive a rainfall of 200–800 mm, and with temperatures between 27 and 30 °C and species belong to genera like *Acacia*, *Balanites*, *Prosopis*, *Salvadora*, etc., predominate (Singh and Chaturvedi 2017). They are divided into two forest types, namely, northern tropical thorn and southern tropical thorn forests. Southern tropical thorn forests are found in Maharashtra, Tamil Nadu and Andhra Pradesh (Gupta n.d.). In Southern India, *Acacia chundra, Acacia planifrons* and *Acacia catechu* form a major part of these forests (Gupta n.d.). Northern tropical thorn forests are found in the semi-arid areas of Rajasthan, Punjab, Haryana, northern Gujarat, Madhya Pradesh, Uttar Pradesh and Delhi (Gupta n.d.). Tropical dry evergreen forests are composed of evergreen trees that have thick leaves and are found in areas that receive a rainfall of 870–1200 mm. They are dominated by species belonging to genera like *Manilkara*, *Memecylon* and others (Singh and Chaturvedi 2017). The forests are found mainly in the coast of Karnataka and also occur along the eastern coast of Andhra Pradesh (Gupta n.d.).

1.1.6 Montane Sub-tropical Forests

The sub-tropical broad-leaved hill forests are largely evergreen and found in areas that receive annual rainfall of 1000–3000 mm (Singh and Chaturvedi 2017). These are divided into, namely, four sub-types. Southern sub-tropical broad-leaved hill forests occur at an altitude range between 1000 and 1700 m in Palani, Tirunelveli, Nilgiri and Mercara hills, and the primary tree species found include *Calophyllum elatum*, *Eugenia* spp., *Dalbergia latifolia*, *Anogeissus latifolia*, *Emblica officinalis*, *Olea dioca* and *Phoenix humilis* (Gupta n.d.). Central Indian sub-tropical hill forests are found at an altitude of about 1200 m in Madhya Pradesh (Pachmarhi), Bihar, Odisha and Pachmarhi hills. *Manilkara hexandra*, *Mangifera* and *Syzygium cumini* are conspicuous trees (Gupta n.d.). Northern sub-tropical broad-leaved hill forests are found in Meghalaya, Nagaland, Arunachal Pradesh, Manipur, Mizoram, Sikkim and West Bengal at an altitude of 1000 to 2000 m, and significant tree species that occur here belong to genera like *Prunus*, *Betula*, *Quercus*, *Castanopsis*, *Alnus* and *Schima* (Gupta n.d.).

Sub-tropical pine forests are forests where pine associations predominate in low altitudes of the Himalayas that receive a rainfall of 1000–3000 mm (Singh and Chaturvedi 2017). These are scattered along Jammu and Kashmir, Haryana, Himachal Pradesh, Punjab and Uttarakhand. *Pinus roxburghii* along with other broad-leaved species are most commonly found in these forests (Gupta n.d.). Sub-tropical dry evergreen forests are spread along the Bhabar tract, Shiwalik hills and hills of Western Himalayas (Gupta n.d.). In Uttarakhand, Himachal Pradesh and Punjab, low xerophytic forests and scrub occur in the foothills of Western Himalayas (Singh and Chaturvedi 2017). *Olea* and *Acacia* spp. are found in these forests (Singh and Chaturvedi 2017).

1.1.7 Montane Temperate Forests

Montane wet temperate forests are closed evergreen high forests that receive a rainfall of 1500–> 5000 mm; in southern India, these are called shola forests with species belonging to *Ternstroemia*, *Ilex* and *Rhododendron*, and in the forests of Eastern Himalayas, *Quercus* forests with *Machilus*, *Acer*, *Rhododendron*, etc. are present (Singh and Chaturvedi 2017). These are further sub-divided into Northern and Southern montane wet temperate forests. Southern montane wet temperate forests are distributed in the high hills of Tamil Nadu and Kerala, like Anamalai, Palni and Tirunelveli hills at an altitude of above 1500 m (Gupta n.d.). Northern montane wet temperate forests are found across Bengal, Sikkim, Assam and Manipur. Himalayan moist temperate forests are found between the sub-tropical pine forest and sub-alpine forests across the Himalayan region at an elevation of about 1500–3300 m (Gupta n.d.). These forests occur in the Central and Western Himalayas, except in the regions that receive an average rainfall less than 1000 mm. They are distributed in Uttarakhand, Darjeeling district of West Bengal, Assam, Jammu and Kashmir, Himachal Pradesh, Punjab and Sikkim (Gupta n.d.).

Species that prevail in these forests include *Quercus leucotrichophora*, *Quercus floribunda*, *Quercus dilatata*, *Quercus incana*, *Quercus semecarpifolia* and *Quercus larginosa*, and several conifers belonging to *Abies*, *Cedrus*, *Picea* and *Tsuga* are also present (Gupta n.d.). Himalayan dry temperate forests are the ones where conifers predominate and are distributed at an altitude between 1700 and 3000 m. They occur in the inner ranges of Himalayas that receive precipitation mostly below 1000 mm (Gupta n.d.). They are found in Ladakh, Lahaul, Kashmir, Chamba, inner Garhwal and Sikkim. Also, conifers like *Pinus* (e.g. *P. gerardiana*), *Picea* and *Juniperus* predominate (Gupta n.d.).

1.1.8 Sub-alpine Forests

Sub-alpine forests occur throughout the Himalayan region at an altitude above 3000 m up to the tree line and receives precipitation of about 83–600 mm (Gupta n.d.). These forests are mainly evergreen, and *Rhododendron* is the most common species found here (Gupta n.d.). Tall conifers are found in these forests. *Betula utilis* is present as the largest deciduous tree in association with species like *Quercus semecarpifolia*, *Sorbus* and *Rhododendron* sp. (Gupta n.d.). Western Himalayan sub-alpine forests are found in Himachal Pradesh, Uttarakhand and Jammu and Kashmir (Gupta n.d.). In the eastern Himalayas, these forests occur above an altitude of 3000 m (Gupta n.d.). They are found in Sikkim, Arunachal Pradesh and West Bengal (Gupta n.d.).

1.1.9 Alpine Forests

Moist alpine scrub forests are found across the Himalayas above the timber line up to 5500 m altitude, and species belonging to *Juniperus* and *Rhododendron* mainly dominate (Singh and Chaturvedi 2017). These forests occur in Uttarakhand, Sikkim, Manipur, Jammu and Kashmir (Singh and Chaturvedi 2017). Dry alpine scrub are xerophytic formations, consisting of mainly dwarf shrubs that receive a rainfall <370 mm annually and are found in areas up to 5500 m altitude. Representative species present are *Juniperus wallichiana*, *Lonicera* spp. and *Potentilla* spp. (Gupta n.d.). These are spread in Himachal Pradesh, Uttarakhand, Jammu and Kashmir and Arunachal Pradesh (Gupta n.d.).

1.2 Forest Resources of India

Population rise and urbanization exceeding sustainable limits have definitely put pressure on Indian forests. But the country has to conserve its forests and has been struggling to achieve its long-term goal of bringing 33% area under forest cover

(Aggarwal 2020). Indian forest sector had an unpredictable journey since 1987 with an increase from 640,819 to 7,12,249 sq..km, i.e. from 19.49% of total land area of the country to 21.67% of the country's geographical area in 2019 (Aggarwal 2020).

About 17% of forest resources in India was densely forested around the early 1990s, and about 50% of the land was not fertile (ENVIS Centre-Maharashtra n.d.). The total area under productive forest cover was approximately 35 million hectares that was around 10% of the total land area (ENVIS Centre-Maharashtra n.d.). But the growing demand of the population increased the pressure on forests for various resources. In the 1980s, all these events led to continuous deterioration of forests that had badly impacted soil conditions (ENVIS Centre-Maharashtra n.d.). In the 1990s, several forested areas received heavy precipitation, and many areas were located at a higher elevation, and some of them were unable to access (ENVIS Centre-Maharashtra n.d.). Around 20% of the total area under forests were in the states of Madhya Pradesh, Arunachal Pradesh, Orissa, Maharashtra, Andhra Pradeshand Uttar Pradesh (ENVIS Centre-Maharashtra n.d.). The National Forest Policy (1988) focused mainly on the significance of forest resources in the economy and ecology of the country. The policy was mainly concentrated on safeguarding constancy of the environment, to maintain ecological balance and to conserve the forests (ENVIS Centre-Maharashtra n.d.). The Forest Conservation Act (1980) went through an amendment in 1988 and ensured stringent measures for protection of forest resources in the country (ENVIS Centre-Maharashtra n.d.).

The forest cover of India was 678,333 sq.km in 2003 and accounted for approximately 20.64% of the total land area (ISFR 2003). According to the canopy density categories mentioned in the India State of Forest Reports (ISFR), Very dense forest (VDF) is the density class with more than 70% canopy density, Moderately dense forest (MDF) is the density class with canopy density of 40–70% and open forest with canopy density of 10–40% (ISFR 2003). In 2003, VDF constituted 51,285 sq. km, i.e. 1.56%; MDF constituted 339,279 sq.km, i.e. 10.32%; and open forest constituted 287,769 sq.km that accounted to 8.76% of the total area (ISFR 2003). Madhya Pradesh had the highest forest cover among all the States/UTs which was 76,429 sq.km, followed by Arunachal Pradesh with 68,019 sq.km forest cover and Chhattisgarh with 55,998 sq.km. According to ISFR Volume I (2019), the total forest cover of the country was 712,249 sq.km which was about 21.67% of the overall land area. The tree cover of the country was assessed as 95,027 sq.km which was 2.89% of the total land area (ISFR 2019). Karnataka had the maximum forest cover with 1025 sq.km followed by Andhra Pradesh (990 sq.km), Kerala (823 sq. km), Jammu and Kashmir (371 sq.km) and Himachal Pradesh (334 sq.km) (ISFR-Volume II 2019). The area covered by mangroves of the country had increased by 54 sq.km, i.e. 1.10%, as compared to the mangrove cover in 2003 (ISFR 2019). In 2003, the mangrove cover had declined by 21 sq.km, as compared to the preceding year (ISFR 2019) (Table 1.1).

Figures 1.1,1.2,1.3 depict the area covered by forests in the States/UTs of India for the years 1987, 2003 and 2019, respectively (Fig. 1.4). The States/UTs where the

Table 1.1 An account of forest cover in States and Union Territories of India

States/UTs	Area covered by forest in the States/UTs in India (1987, 2003 and 2019) Area in sq.km		
Year	1987	2003	2019
Andhra Pradesh	49,573	44,419	29,137
Arunachal Pradesh	64,132	68,019	66,688
Assam	25,160	27,826	28,327
Bihar	28,482	5558	7306
Chhattisgarh	-	55,998	55,611
Delhi	15	170	195.44
Goa	1240	2156	2237
Gujarat	11,991	14,946	14,857
Haryana	513	1517	1602
Himachal Pradesh	12,480	14,353	15,434
Jammu and Kashmir	20,905	21,267	21,122
Jharkhand	-	22,716	23,611
Karnataka	32,268	36,449	38,475
Kerala	10,292	15,577	21,144
Madhya Pradesh	1,30,099	76,429	77,482
Maharashtra	45,616	46,865	50,778
Manipur	17,475	17,219	16,847
Meghalaya	16,466	16,839	17,119
Mizoram	19,084	18,430	18,006
Nagaland	14,394	13,609	12,486
Odisha	53,253	48,366	51,619
Punjab	943	1580	1849
Rajasthan	12,758	15,826	16,630
Sikkim	2756	3262	3342
Tamil Nadu	17,472	22,643	26,364
Tripura	5953	8093	7726
Uttar Pradesh	31,226	14,118	14,806
Uttarakhand	-	24,465	24,303
West Bengal	8432	12,343	16,902
Telangana	-	-	20,582
A and N Islands	7601	6964	6743
Chandigarh	2	15	22.03
Dadra and Nagar Haveli	238	225	207
Daman and Diu	0	8	20.49
Ladakh	-	-	2490
Lakshadweep	0	23	27.1
Puducherry	0	40	52.41
Grand total	6,40,819	6,78,333	7,12,249
Per cent	19.49	20.64	21.67

Source: ISFR (1987, 2003 & 2019); www.frienvis.nic.in

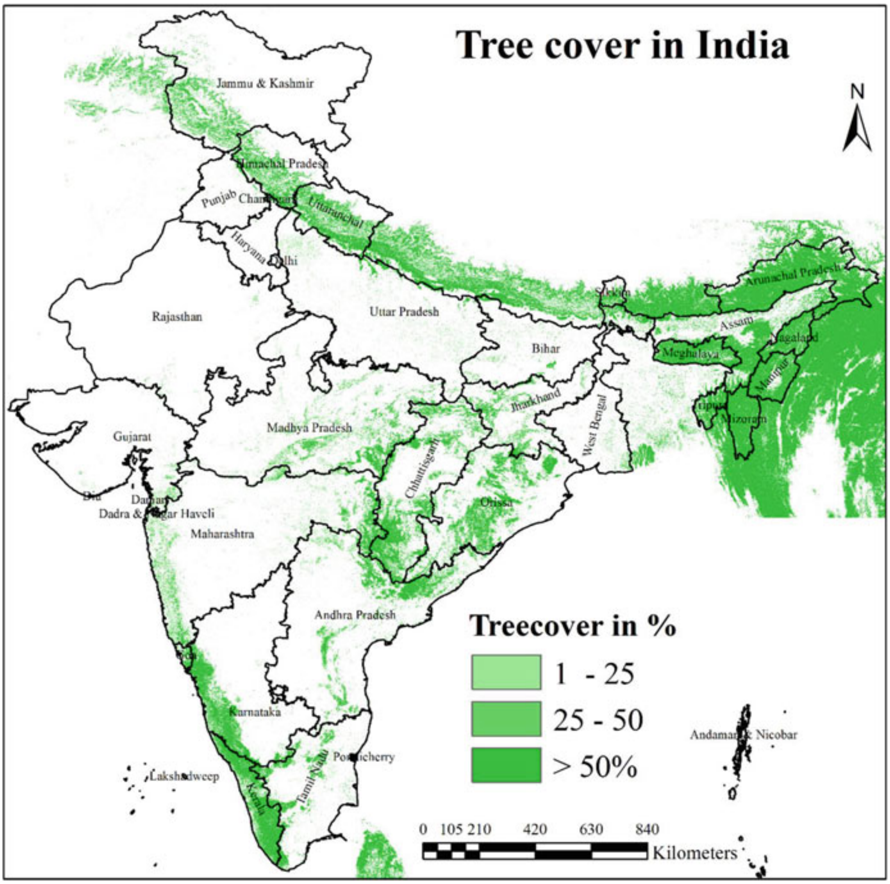

Fig. 1.1 Tree cover in India 2020

area covered by forest were more in the year 2019 as compared to that in 2003 with Goa, Haryana, Himachal Pradesh, Jharkhand, Karnataka, Kerala, Madhya Pradesh, Assam, Bihar, Delhi, Maharashtra, Meghalaya, Odisha, Punjab, Rajasthan, Sikkim, Chandigarh, Tamil Nadu, Uttar Pradesh, West Bengal, Daman and Diu, Lakshadweep and Puducherry. On the other hand, Gujarat, Jammu and Kashmir, Manipur, Mizoram, Nagaland, Tripura, Andhra Pradesh, Arunachal Pradesh, Chhattisgarh, Uttarakhand, Andaman and Nicobar Islands, Dadra and Nagar Haveli are the States/UTs where the forest cover was less in 2019 as compared to that in 2003. Forest cover showed an increase from 20.55% in 2001 to 20.64% in 2003, also, there was an increase in forest cover from 21.34% in 2015 to 21.54% in 2019. The observed positive change in the area covered by forests could be mainly accounted to the management strategies that comprised of activities such as afforestation (Kumari et al. 2019). The success could also be attributed to many other measures involving community participation that ensured betterment of the conditions (Kumari et al.

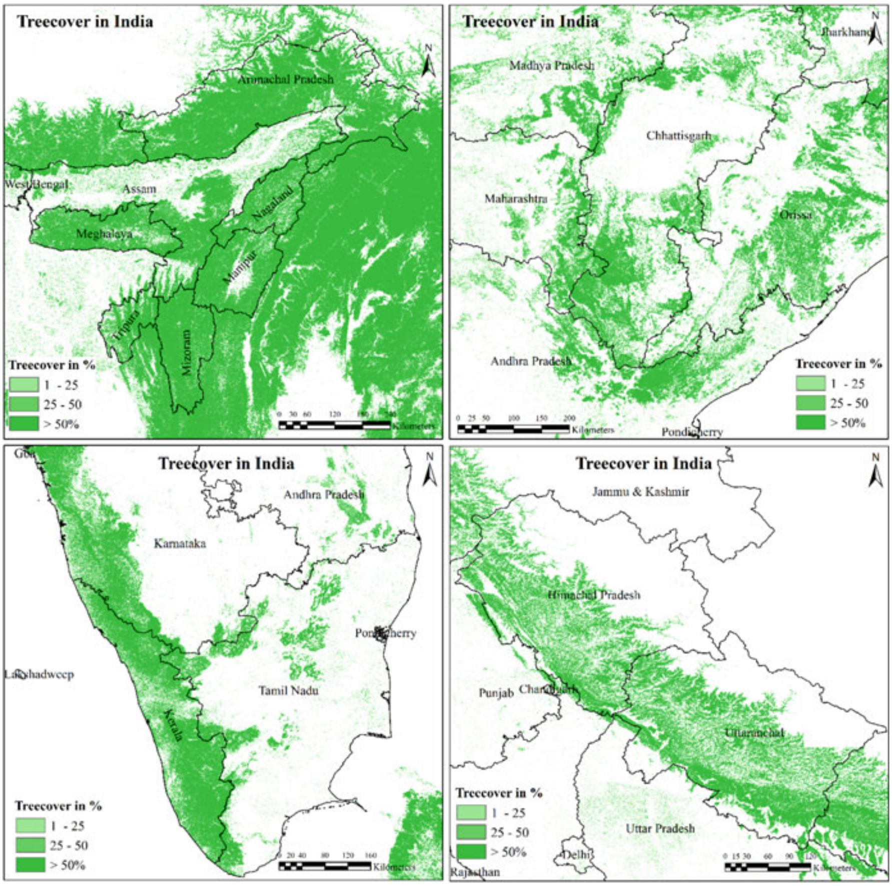

Fig. 1.2 Major forest cover areas in India 2020

2019). The assessment of forest cover of 2019 showed an upsurge of 3976 sq.km. (0.56%) in the area covered by forests, 1212 sq.km (1.29%) of area covered by trees and 5188 sq km (0.65%) of area covered together, as compared to the assessment of forest cover in 2017 (ISFR 2019).

According to Fig. 1.5, Madhya Pradesh was the state which had the highest forest cover in 1987. Out of the total 64.2 million hectares of forest cover, 12.77 million hectares, i.e. one fifth, was in Madhya Pradesh that accounted for about 19.9% (The State of Forest Report, 1987) (Figs. 1.6 and 1.7). Based on the ratio of percentage of recorded forest cover to the geographical area, Andaman and Nicobar Islands, Manipur, Nagaland, Tripura and Arunachal Pradesh had forest cover more than 50%; Assam, H.P., M.P., Meghalaya, Odisha, Sikkim, Dadar and Nagar Haveli had 33 to less than 50%; Andhra Pradesh, Kerala, Maharashtra, Goa, Daman and Diu had 20 to less than 33%; Karnataka, Rajasthan, Bihar, Tamil Nadu, UP and West Bengal had 10 to less than 20%; Gujarat, Haryana, Jammu and Kashmir, Punjab, Delhi and

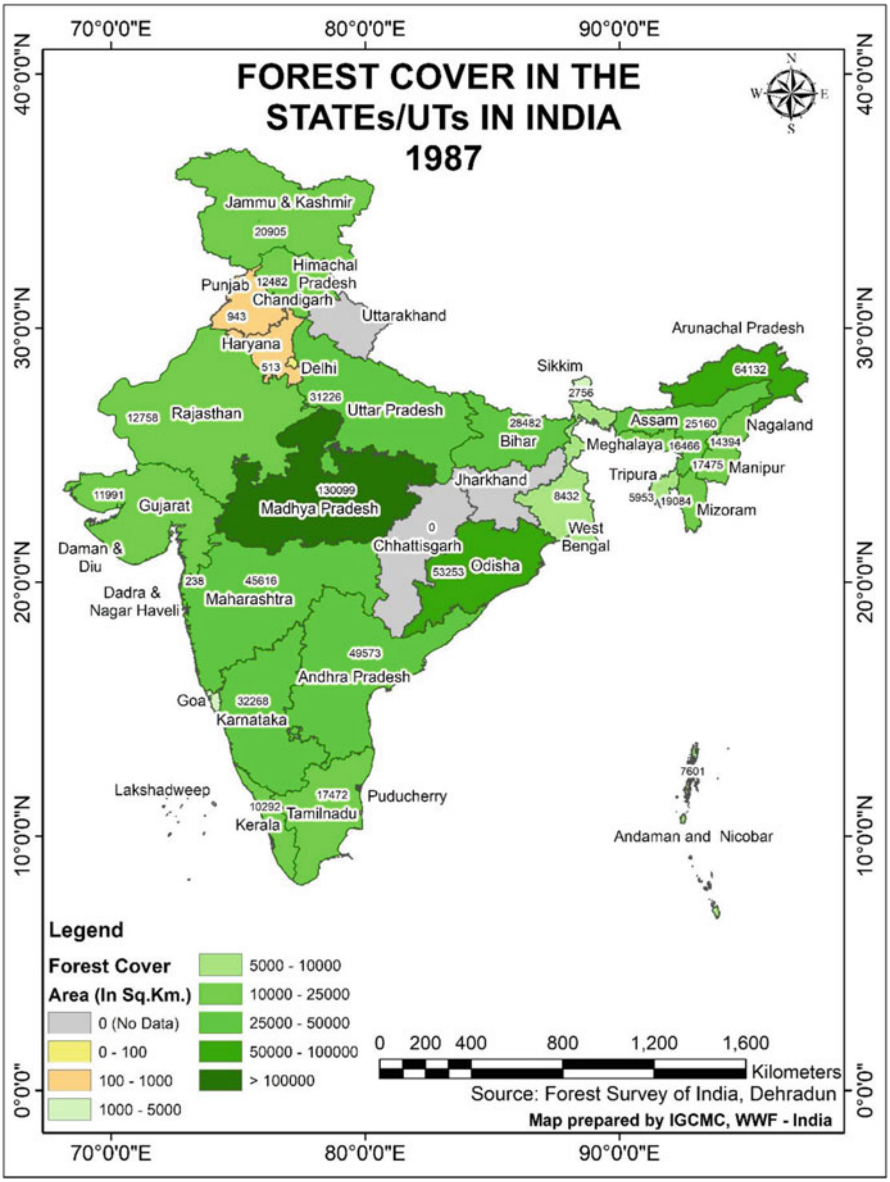

Fig. 1.3 Area covered by forest in the States/UTs in India (1987)

Chandigarh had forest cover less than 10% (The State of Forest Report, 1987). The area covered by mangroves was observed to be 0.15% of the total geographical area of the country, i.e. 4975 sq.km, in 2019 (ISFR 2019).

Very dense mangrove cover constituted 29.66% of the area (Fig. 1.8), i.e. 1476 sq.km; moderately dense mangrove comprised an area of 1479 sq.km,

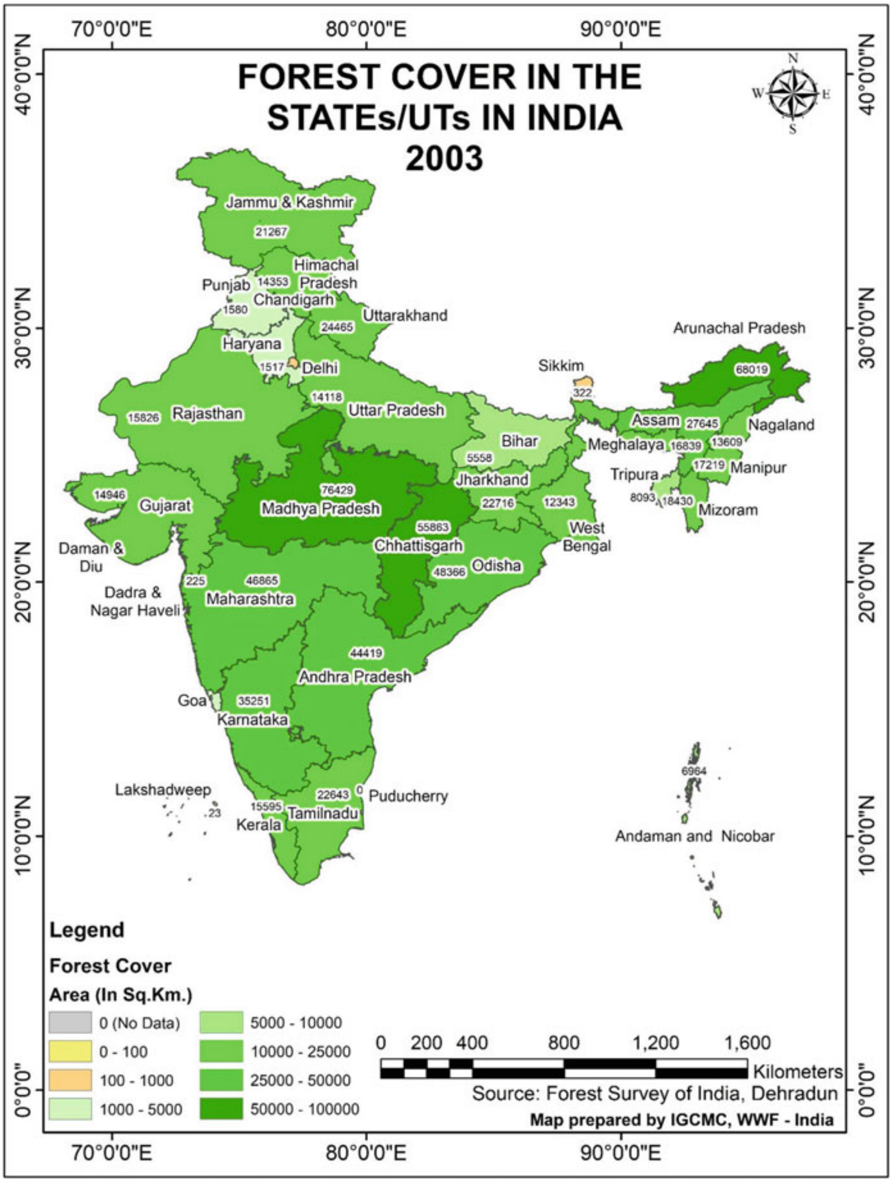

Fig. 1.4 Area covered by forest in the States/UTs in India (2003)

i.e. 29.73%; and open mangroves covered an area of 2020 sq.km, i.e. 40.61% (ISFR 2019). An increase in area of 54 sq.km has been recorded in the area covered by mangroves in 2019 as compared to the area covered in 2017 (ISFR 2019). In 2003, area covered by mangroves in the country constituted an area of 4461 sq.km., i.e. 0.14% of geographical area (ISFR 2003), out of which, an area of 1162 sq.km

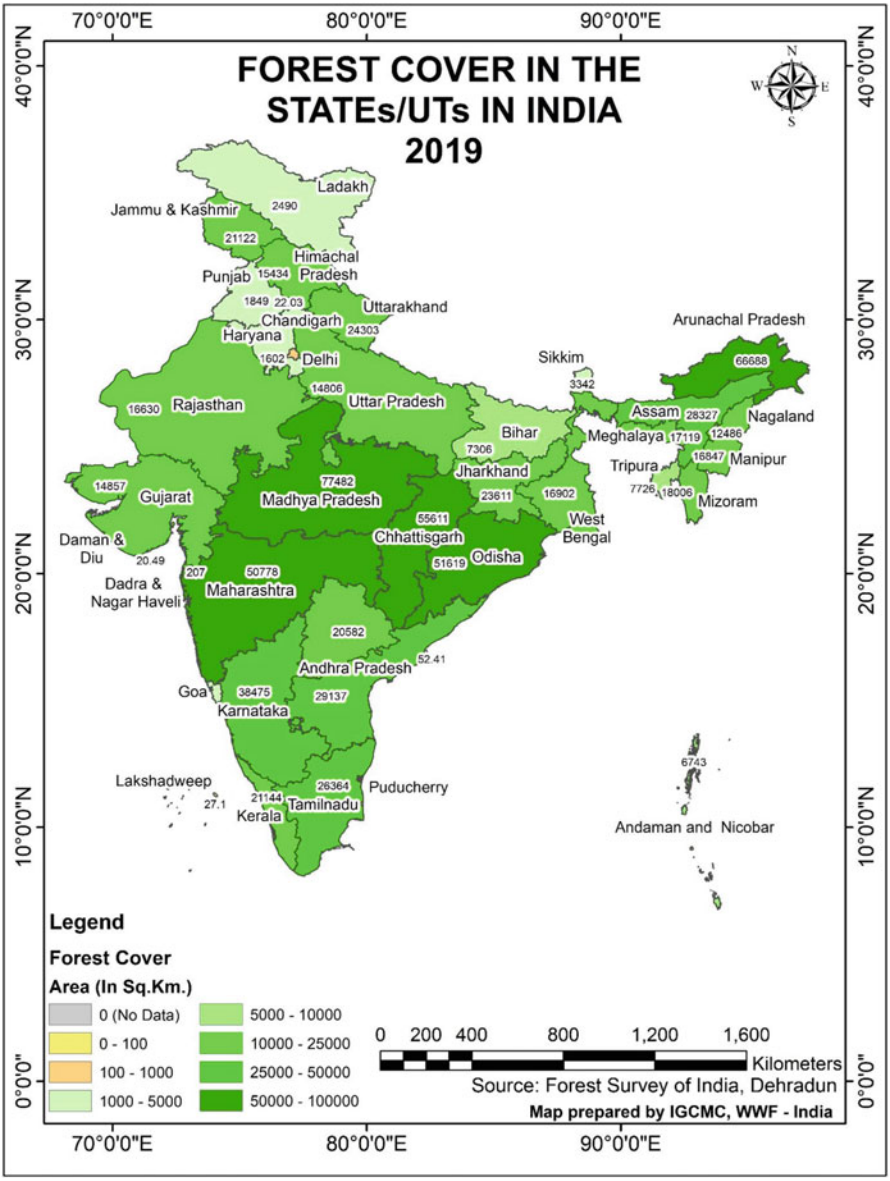

Fig. 1.5 Area covered by forest in the States/UTs in India (2019)

was covered by very dense mangroves, 1657 sq.km area was covered by moderately dense mangroves and 1642 sq.km area was comprised of open mangroves (ISFR 2003). Also, there was an overall decrease of 21 sq.km. in the mangrove cover of the country when compared with that in 2001 (ISFR 2003) (Fig. 1.9).

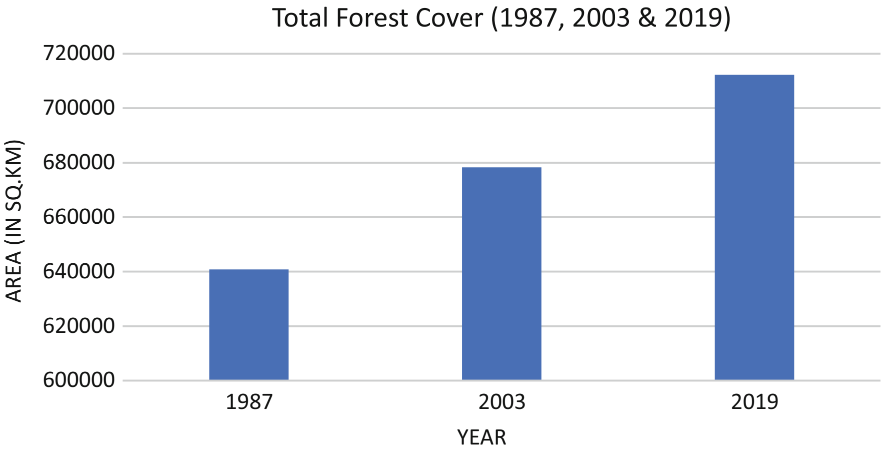

Fig. 1.6 Graph showing total forest cover of India in 1987, 2003 and 2019

1.3 Protected Forest Regions

Protected areas are regions where interference by humans and exploitation of resources are minimal and limited through implementation of certain rules and regulations (Protected Area Networks of India n.d.). There are several types of protected areas, which are classified based on the level of protection offered in them according to the laws formulated by every country or based on the regulations imposed by various international organizations involved (PA Networks of India n.d.). Marine protected areas are protected areas, where their boundaries include some area/portion of ocean, and trans-boundary protected areas are the ones that overlap multiple countries which remove the borders inside the area for the purpose of their conservation and other activities related to economy of the country. The other protected areas are national parks, wildlife sanctuaries, conservation reserves and community reserves. Protected areas that act as buffer zones to or migration corridors between national parks, wildlife sanctuaries, reserve and protected forests of India include community reserves and conservation reserves (WWF ENVIS n.d.). In India, there are 566 wildlife sanctuaries and 104 national (as of March 2021) (WWF ENVIS n.d.) (Table 1.2).

Reserve forests in India represent an immense diversity of India's wildlife (Reserve Forests in India n.d.). There is a higher degree of security in reserve forests as compared to protected forests because reserved forests in India do not grant permission for grazing or hunting within its limits, while protected forests allow with some degree of restrictions (Reserve Forests in India n.d.; ENVIS Centre on Wildlife & Protected Areas n.d.). Reserve forests as well as protected forests in India are declared by the respective state governments unlike national parks or wildlife sanctuaries. However, protected forests and reserve forests are considerably different (Reserve Forests in India n.d.). Typically, protected forests are of two types, namely, protected forests and un-demarcated protected forests (Reserve Forests in India n.d.).

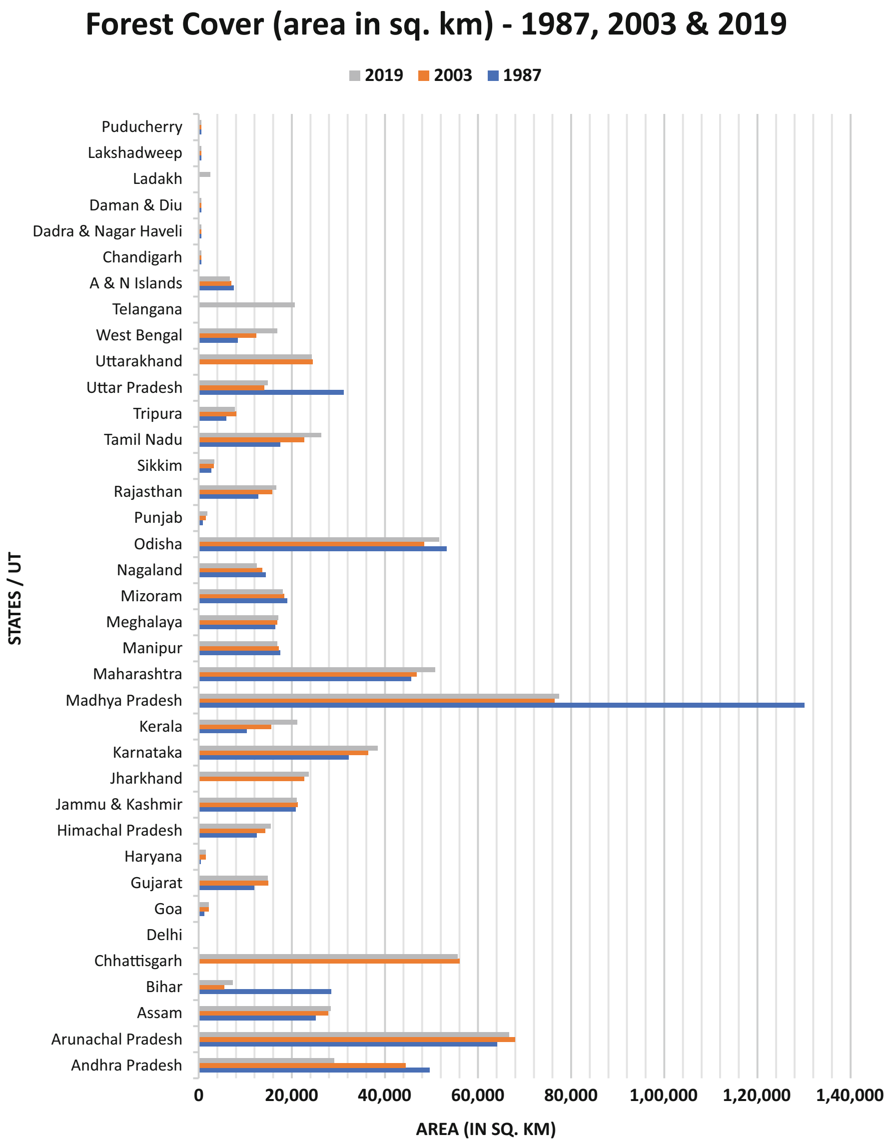

Fig. 1.7 Graph showing total forest cover of the States/UTs in 1987, 2003 and 2019

1.4 Major Threats to India's Forest Resources

India is among one of the eight countries that is part of the South Asian subregion. Forests in India are exposed to various pressures already, and it can get worsened due to climate change that can cause vegetation shifts (Chaitra et al. 2018). Some of

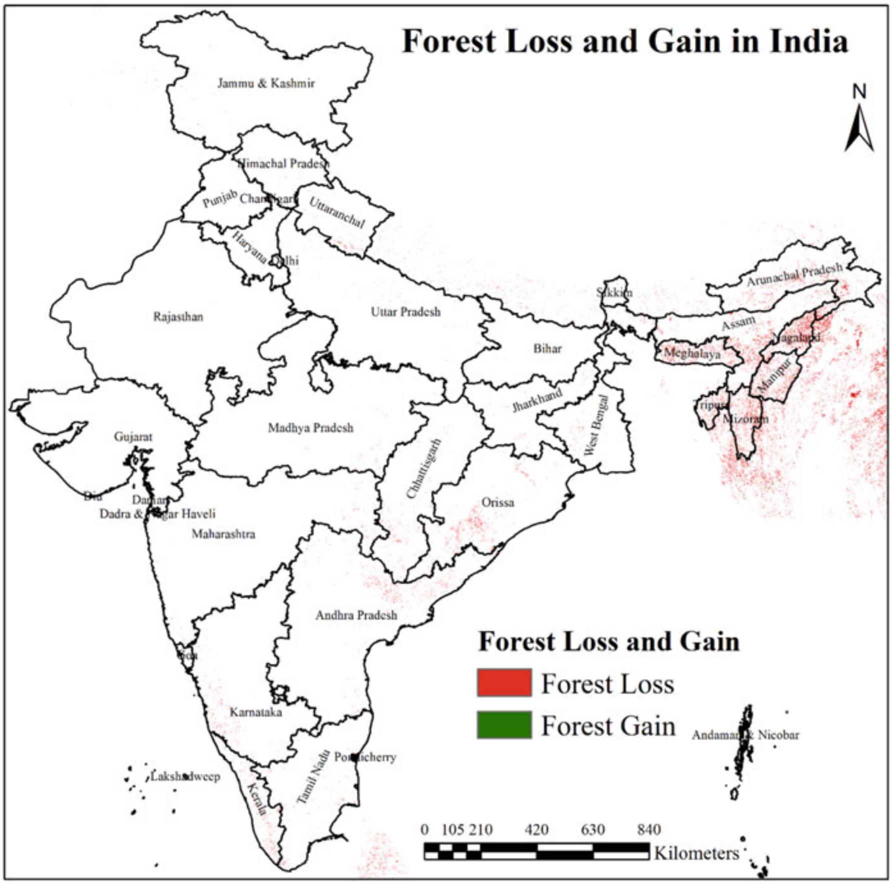

Fig. 1.8 Forest cover loss and gain in India during 2001 to 2020

the profound impacts of climate change include changes in distribution of forest, net primary productivity (NPP) and soil organic carbon (SOC) (Chaitra et al. 2018). Alterations in productivity, vegetation composition and distribution are caused due to changes in forest edges (Chaitra et al. 2018). The prime reasons for such changes would be changes in plant phenology (Chaitra et al. 2018). Phenological changes are brought about by changes in temperature and climatic patterns (Chaitra et al. 2018). An increase in forest fires and pests is also predicted to become more common (Chaitra et al. 2018). According to studies, the frequency and intensity of forest fires will increase progressively with these changes (Chaitra et al. 2018). Increasing demand for forest resources in order to meet multiple and conflicting needs of the society has imposed a number of threats and pressures on forests (Chaitra et al. 2018). Deforestation is a major concern, but degradation arising mainly due to extreme human pressures remains the foremost problem. Clearance of forests in

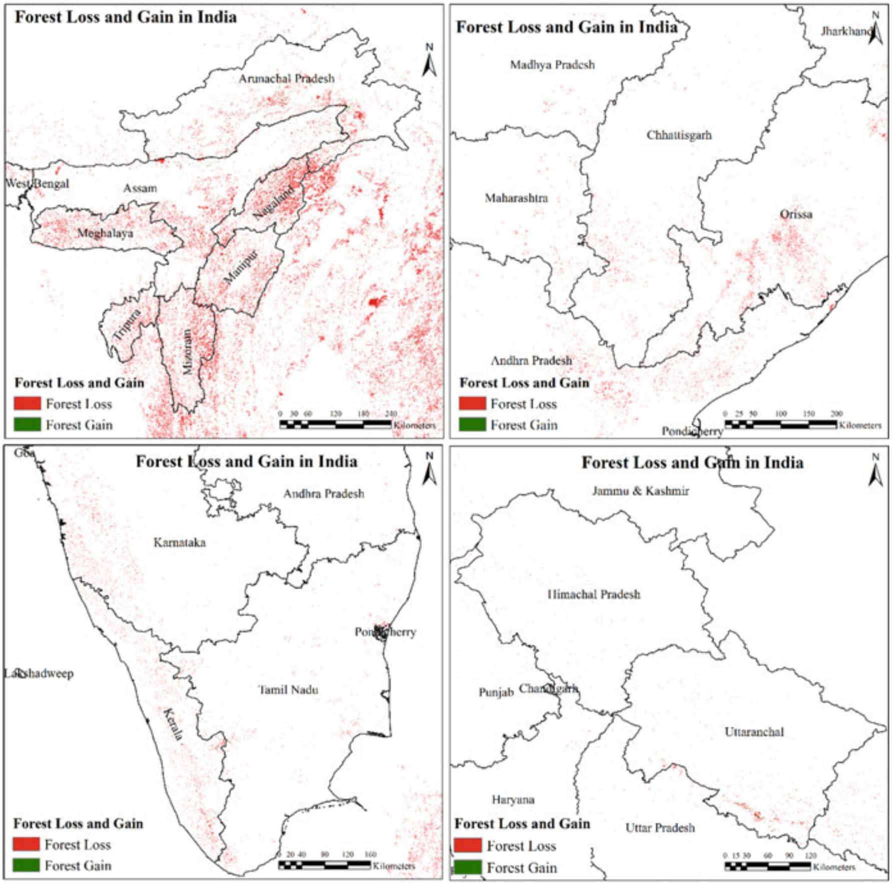

Fig. 1.9 Major forest cover loss and gain that had occurred in India during 2001–2020

any particular area are caused by several anthropogenic pressures such as extensive extraction of resources for various necessities (Chaitra et al. 2018). The necessities might include food production, agricultural activities, etc. It is indeed very difficult to generalize these parameters due to the diverse regulations related to demography, economy and policies of various countries (Chakravarty et al. 2012). Unsustainable use and over-exploitation of forest resources are the main reasons for deforestation (Chakravarty et al. 2012). Besides industrialization and urbanization, a considerable percentage of the rural population is still dependent on forests for fulfilling their livelihood necessities (Chakravarty et al. 2012). These livelihood necessities are one of the principal reasons for less growth of forest stocks in the country (Chakravarty et al. 2012). Uncontrolled exploitation and degradation will continue to impact the future status of the forests, and it might lead to serious implications in the future (Chakravarty et al. 2012). It is evident that over the previous decade, there has been remarkable signs of favourable landscape changes such as afforestation and forest

Table 1.2 Area and the number of protected areas of India from 2000 to 2020 (December 2020)

Year	No. of national parks	Area under national parks (km^2)	No. of wild life sanctuaries	Area under wildlife sanctuaries (km^2)	No. of community reserves	Area under community reserves (km^2)	No. of conservation reserves	Area under conservation reserves (km^2)	No. of protected areas	Total area under protected areas (km^2)
2000	89	37803.10	485	108862.50	-	-	-	-	574	146665.60
2006	96	38392.12	503	111229.48	1	0.31	4	42.87	604	149664.78
2007	98	38428.88	507	111529.04	5	21	7	94.82	617	150073.74
2008	99	39441.74	510	113123.35	5	21	45	1259.84	659	153845.93
2009	99	39441.74	512	113395.36	5	21	45	1259.84	661	154117.94
2010	102	40283.62	516	113842.87	5	21	47	1382.28	670	155529.77
2011	102	40283.62	518	113998.75	5	21	52	1801.29	677	156104.66
2012	103	40500.13	526	114933.44	5	21	59	2012.93	693	157467.50
2013	102	40500.13	532	117123.63	19	30.94	64	2232.61	717	159887.31
2014	103	40500.13	535	118290.66	43	58.22	64	2232.61	745	161081.62
2015	103	40500.13	541	118866.44	44	59.51	71	2548.82	759	161974.90
2016	103	40500.13	543	118917.71	45	59.66	72	2566.20	763	162043.70
2017	103	40500.13	544	118931.80	46	72.61	76	2587.95	769	162092.49
2018	104	40501.13	544	118931.80	46	72.61	77	2594.03	771	162099.47
2019	101	40,564.03	553	119,756.97	163	833.34	86	3858.25	903	1,65,012.59
2020	104	43,716	566	1,22,420	214	1302	97	4483	981	1,71,921

Source: National Wildlife Database, Wildlife Institute of India regrowth (Chakravarty et al. 2012). Management strategies focus mainly on restoration and wise use of the forest that would maintain sustainability and quality of the resources for future services (Chakravarty et al. 2012). In view of the severe resource crunch, there is a need to implement latest technologies to improve energy efficiency and promote sustainable resource use to guarantee that these are reasonable and feasible (Chakravarty et al. 2012). A significant focus could be to make different stakeholders, especially local communities, farmers, forest dwellers, etc., aware about such technologies, which have remained outside the mainstream of such changes (Chakravarty et al. 2012). Strengthening a unified land use framework that can sustain ecosystem processes along with the adoption of a green economy will be key (Chakravarty et al. 2012).

1.5 Initiatives and Policy Measures by the State

There are many initiatives and policy measures adopted by various State Governments of India towards the conservation of forest resources. There are many laws, policies, rules, regulations and guidelines that have been formulated, which are being imposed in order for protection of forest resources in India (Kumari et al. 2018).

Besides these, the Indian Government has also established institutions and authorities like the Forest Survey of India (FSI), under the Ministry of Environment, Forest and Climate Change, that performs the preliminary work of gathering and evaluating the forest assets of India through a nationwide survey (Kumari et al. 2018). This survey provides a consolidated repository of information on the spatial and temporal cover of forested areas in India (Kumari et al. 2018). The survey conducted by FSI assists in assessing the parameters and reasons leading to the gain or loss in forest cover of any specific region of India (Kumari et al. 2018). In 2009, a council called the Compensatory Afforestation Fund Management and Planning Authority (CAMPA) was formed by the Government of India. It acted as a National Advisory Council under the chairmanship of the Hon'ble Union Minister of Environment, Forest and Climate Change for the monitoring and evaluating compensatory afforestation activities and to provide technical assistance (Kumari et al. 2018). The role of this council was to ensure important afforestation and activities for regeneration of forests in order to compensate for conversion of forest land for non-forest activities (Kumari et al. 2018). Schemes such as Integrated Forest Protection Scheme (IFPS) were formulated by the government to ensure protection from forest fires (Kumari et al. 2018). This scheme was developed by integrating forest conservation principles and measures with forest fire protection and management techniques (Kumari et al. 2018). The Government of India has also launched numerous other missions and programmes to promote forest protection such as National Mission for a Green India (NMGI) and National Afforestation Programme (NAP) (Kumari et al. 2018). The main objective of NMGI was to enhance the value of 5 million hectares of degraded forests and to convert another 5 million hectares of non-forested areas into productive forest through the application of social and farm forestry (Kumari et al. 2018). One of the other prime focus of the National Afforestation Programme was to improve forest resources with community participation, focusing primarily on the betterment of the livelihoods of forest communities living inside and near the forests, specifically the poor (Kumari et al. 2018).

For a very long time, the Ministry of Environment, Forest and Climate Change has been confident in empowering women to strengthen their role in the protection of forest resources at local community levels (Kumari et al. 2018). The National Forest Policy acknowledged the requirement of involving women in forestry schemes, for the first time (Kumari et al. 2018). The Joint Forest Management (JFM) Policy (1990) authorized the presence of not less than 40% of woman representatives in the general body and 50% presence in the executive body of local forestry institutions like the JFM committees (Kumari et al. 2018). In 2002, the Biodiversity Authority of India reframed structure of the local Biodiversity Management Committee (BMC) (Kumari et al. 2018). It instructed the reservation of a minimum of one-third of the members in BMCs to be women (Kumari et al. 2018). The understanding about the role of women in local-level forest conservation measures and its implementation has led to the betterment of the management of forests in rural localities of India (Kumari et al. 2018).

1.6 Forest Conservation and Protection Policies

The Government of India has been constantly pitching for consistent and cohesive efforts for conserving forest resources (Kumari et al. 2018). They not only have implemented measures for conservation of the current forest cover but also have initiated several measures to increase the forested areas of India as well (Kumari et al. 2018). Some of these policies are as follows (WWF-India, n.d.; MoEF & CC, 2019):

- In 1952, a National Forest Policy (NFP) was framed for the revamping of the policy in view of the differences that had taken place since the assertion of the policy on forests in 1894. Forests in the country, whether it is under state or private ownership, were categorized into four classes that are protection forests, national forests, village forests and tree lands.
- The National Commission on Agriculture (NCA) also indicated that "there should be a change over from the conservation-oriented forestry to (a) more dynamic programme of production forestry". The NCA mentioned that the NFP should be grounded on optimization of forest resources for their use in the form of services and goods. It emphasized on prevention of erosion and denudation and hence maximizing forest productivity and supplementing potential to generate employment for ensuring national prosperity.
- The National Forest Policy of 1988 (NFP) was formulated in order to ensure that the regulations mentioned under the policy provide a comprehensive basis for

conserving forests. It also signified a radical change from the previous policies which started to form by introduction of Joint Forest Management in India in 1990.

- The Forest Conservation Act of 1980 is the most significant legislative initiative in the Indian history to reduce deforestation mainly triggered by the conversion of forests into non-forest uses. Under this Act, no State Government has the authority to permit such conversion without securing approval from the Central Government.
- The Biological Diversity Act (BDA) (2002) was formulated to control access to genetic resources and associated sharing besides development of policies and programmes that enable conservation and protection of biological resources and associated knowledge on a long-term basis. The National Biodiversity Authority (NBA), set up at Chennai on 1 October 2003 as per the provisions of the BDA, is accredited to facilitate implementation of the Act.
- The Indian Forest Act of 1927 (IFA) and its progeny were implemented in various states and provide a framework for the supervision of forests in India, and "The preamble to the Act states that the Act seeks to consolidate laws relating to forests, the transit of forest produce and the duty leviable on timber and other forest produce".
- In India, Joint Forest Management (JFM) emerged as an important measure in managing forest resources. It recognizes the livelihood and sustenance needs of the people through the concept of "care and share". The programme authorizes local people to actively participate as partners in the effective management of forest resources and sharing the benefits obtained from its protection and management. The JFM approach enhances returns, minimizes conflicts and links forest development works with the overall development of land resources. It also promotes building of technical and managerial capacity at the grassroots level.

1.7 NGOs, Institutions and Public Participation

It is observed that there is an increasing trend of environmental awareness among a diverse range of stakeholders that includes individuals and communities within the Asia-Pacific region (United Nations ESCAP n.d.). This growing awareness related to environmental issues is the outcome of various educational programmes and campaigns organized by foremost special interest groups concerned about the environment (United Nations ESCAP n.d.). Among them are non-governmental organizations (NGOs) that function at the international, regional and national levels, as well as institutions that focus on the empowerment of women, indigenous peoples and youth groups and other establishments that work for the betterment of communities (United Nations ESCAP n.d.). The wide array of activities undertaken by environmental NGOs and other major groups has increased during the past few years (United Nations ESCAP n.d.). Local, national and regional NGOs have emerged as mainstream impact creators in both development and conservation activities in the region (United Nations ESCAP n.d.). Some aspects that NGOs and other institutions which deal with environmental issues work on are (United Nations ESCAP n.d.):

- At the community level, they provide assistance to forest communities for attainment of basic needs and facilities.
- They help in identification of issues, generating awareness and facilitation of information to communities.
- They help various communities to express their issues and requirements and bring those to the attention of stakeholders who can effect change.
- They help in defending both the environmental and developmental rights of forest communities and capacity building of communities for management of their natural resources sustainably.

Environmental NGOs play a significant role in providing assistance to minimize the gaps in conservation strategies. Such gaps are lessened by conduction of researches that enable policy development, building institutional capacity and facilitating independent dialogue with civil society to help people achieve sustainable livelihoods (WWF ENVIS n.d.). A few important NGOs worth mentioning are the World Wide Fund for Nature India (WWF-India), The Energy and Resource Institute (TERI), Indian Environmental Society (IES), Centre For Environmental Studies (CES), Indian Council of Forestry Research and Education (ICFRE) and many others (WWF ENVIS n.d.). For example, WWF-India has been working on tiger conservation in the Sundarbans since the beginning of the Project Tiger in 1973 (WWF-India, n.d.). Under the programme, WWF-India provided technical inputs to the State Forest Department towards the development of management plans and scientific methodology for research, trained and conducted workshops for staff and worked towards the implementation of conservation strategies and promoting community participation (WWF-India, n.d.). Involvement of communities in conservation of forests ensures that they become aware about the measures being taken for their betterment. This realization will enable them to contribute their part towards forest protection, and they will allow them in availing the benefits of the process that will help in sustaining their livelihood.

1.8 Conservation, Monitoring and Management Perspectives

Protected area management dominates among the mainstream methods applied for biodiversity conservation and for efficient management that in turn is crucial to prevent the loss of biodiversity (Addison et al. 2016). Management of forest resources based on evidence can enable appropriate management of natural resources by involving the finest accessible evidence to support management decisions and to validate effectiveness of management practices (Addison et al. 2016).

Emergence of evidence-based management has been noticed over the years. It acts as an approach that will respond to the necessity of increased transparency and stimulate positive conservation outcomes (Addison et al. 2016). The main objective of evidence-based management is to support conservation practitioners to decide as and when to interfere into a system when something undesirable happens (Addison et al. 2016). State-dependent management often backs up management that is evidence-based, where apt management practices that depend on the current status of the system (Addison et al. 2016). Assessment of a system that shifts into an undesirable status is possible using state-dependent management, provided that the decision-maker has a good understanding about ecosystem processes (Addison et al. 2016). Eventually, successful conservation of biodiversity is possible when it's in a better state before the intervention or if the threats and pressures have decreased (Stephenson 2019). Project managers and other stakeholders should have a better understanding about the impacts of their involvement and possible outcomes (Stephenson 2019). They need to recognize which strategies and actions are best suited and what require improvement, so that they can learn and adapt in order to be able to frame a better future (Stephenson 2019). Monitoring of conservation projects seems to be insufficient due to weak plans and indicators, short-lived monitoring schemes and an absence of capacity and feasible budgeting for collection of data and implementation at relevant scales (Stephenson 2019). Inadequate planning and monitoring can take a toll on the potential for sustainability, knowledge sharing and systematic learning, which are among the most important factors that accelerate the pace of conservation (Stephenson 2019). Therefore, good planning is of utmost importance for good monitoring (Stephenson 2019). Majority of the planning systems emphasize on formulation of an inspirational vision with a quantifiable goal and objectives, based on the issues under concern, and how they are associated with each other (Stephenson 2019). Hence, only when all these parameters are considered and incorporated can conservation be effective.

1.9 Conclusion

India is a megadiverse country that is blessed with a large amount of floral and faunal diversity. But there are many issues that ring an alarm, indicating the fact that efforts have to be made in order to overcome threats that impact the forests. Moreover, for a country like India that is highly resource dependent, austere degradation of forests may lead to long-term consequences that might hamper the economy, food and water security and climate solutions (Roy 2020). India is a country that is already most vulnerable to climate change (Roshni et a., 2022; Roy 2020). Also, a destabilized potential of forests in maintaining ecological balance due to rapid increase in deforestation would only accelerate the frequency and intensity of impacts such as unexpected rains in monsoon, severe droughts and other related impacts (Roy 2020). The consequences of deforestation are universal and can affect the forest-dependent communities adversely (Kumari et al. 2019). The impact of desertification on forests could not be understood properly as there is inadequacy in available data that is considered to be one of the major drawbacks (Kumari et al. 2019).

Deforestation and forest degradation had caused a significant reduction of about 12.6% in the growing forest stocks (Roy 2020). This reduction accounts for about nearly 172 tonnes of carbon emissions according to World Resources Institute (WRI) over the last two decades (Roy 2020). A study conducted by WRI revealed that India has lost 122,748 hectares of forests during 2001 to 2020 (Roy 2020). There are many detrimental impacts of deforestation which had to be curtailed through implementation of various mitigation measures that will also help in reducing the negative impacts in the near future. The Indian Government has been making prominent efforts for protection of forest resources by conserving forest cover (Kumari et al. 2019). They have also initiated several measures to increase the forest cover of the country (Kumari et al. 2019). The strategies for mitigating deforestation require efficient implementation and proper demarcation of the roles assigned to national, state and municipal governments along with active participation of NGOs and other private organizations (Kumari et al. 2019). Sustainable alternatives for Jhum cultivation can be adopted to enhance agriculture and forest productions that will lead to mitigation of deforestation (Kumari et al. 2019). The yet another strategy that can be implemented to slow down the rate of deforestation is through following sustainability in agroforestry, logging and agro-pastoral production systems (Kumari et al. 2019). This will ensure application of forest management practices that are ecologically, economically and socially sustainable (Kumari et al. 2019). Forest certification can also act as an effective approach to curb deforestation. It can be achieved through a method with which producers can identify worth of their products in the marketplace and, in turn, receive greater market approachability and higher rates for their products that follow certain sustainable standards of forestry (Kumari et al. 2019). There could be many other efforts and strategies to be implemented by involving community participation that would benefit the communities' livelihood and, at the same time, conserve forests. Indigenous knowledge acquired by forest dwellers can also play a prominent role in the implementation of sustainable management practices for forest conservation. An eco-centric approach should be followed for protection of forests so that the rich diversity of our country is not only maintained but also flourishes.

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Chapter 2
Assessment of Carbon Sequestration Using InVEST Model in Delhi, India

Supreet Kaur, Deepakshi Babbar, Omar Sarif, Aparajita Ghatak, and Abolfazl Jaafari

Abstract Urban growth legitimately influences the ecological development of the territory, which directly influences global climate change. Delhi is among one of the five megacities of India, inhabiting 29 million of populace, which might surpass Tokyo as the world's biggest agglomerations by 2028 according to the World Urbanization Prospects 2018. Carbon management in vegetation is an inescapable significant strategy to balance the carbon emanation in the atmosphere mitigating climate change. Woodland is the major earthbound carbon sink on the earth. Carbon sequestration from the atmosphere takes place primarily in the stable carbon reservoirs of soil profiles in forests. Assessment of carbon pools not only determines the growth rate of forests but also objectively defines the importance of capitalizing the natural assets which further aid in defining the specific areas of concern helping in policymaking. Using the InVEST model for the years 2000 and 2020, the current study attempts to quantify carbon sequestration based on the change in total carbon in two separate timeframes. The InVEST model has aggregated the biophysical measure of carbon which puts away in four carbon pools based on the prepared

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LULC maps. An increase in the Forest and Tree Cover of Delhi has been observed on a continuous premise from the year 2000 to 2020. The results show that the total amount of carbon sequestered in the respective time period over Delhi is 6.9×10^5 Mg. The improved forest management practices and various afforestation and reforestation programs conducted by the government of Delhi led to strengthening the carbon storage capacity of the Delhi region. According to the analysis, the economic potential of carbon sequestered between 2000 and 2020 is about 106.27 million dollars. The outcomes show the potential for reforestation with the native species as a significant function in forest management to improve carbon sequestration capability of the urban wood ecosystem of Delhi and demand access to renewable energy to decrease the carbon loss due to the developmental activities.

Keywords Carbon sequestration · LULC · Forest · Biomass · InVEST model

2.1 Introduction

The global energy balance is vastly being governed by greenhouse gases; their insignificant concentration change in the atmosphere may hamper the climatic conditions on Earth. Carbon dioxide (CO_2) among greenhouse gases (GHGs) makes the largest contribution from human activities (Lal and Singh 2000; Mathieu 2006). Mathieu in 2006 and Dentener et al. 2013 have concluded that the increasing atmospheric burden of well-mixed GHGs resulted in a 9% increase in their radiative forcing from 1998 to 2005 and 7.5% increase in the radiative forcing from 2005 to 2011 respectively, where CO_2 contributes 80% alone. In recent years, rising CO2 levels in the atmosphere have compelled countries to analyze their contributions to CO_2 sources and sinks, as well as the mechanisms that govern CO_2 buildup in the atmosphere (Lal and Singh 2000). The stability of atmospheric CO_2 concentrations is required for efforts to manage climate change. This can only be accomplished by rapidly reducing global CO_2 emissions (Le Quéré et al. 2009). Meeting the ultimate goal of the United Nations Framework Convention on Climate Change (UNFCCC) will require measures to CO_2 emissions by deploying existing and new technologies where GIS and remote sensing can play vital roles in the most effective manner.

The carbon cycle is a dynamic process where the vegetation (including the forest ecosystem, fuelwood plantation, and other harvested agricultural products) absorbs a large amount of CO_2 from the atmosphere via photosynthesis and store a small fraction of assimilated carbon in the above- (vegetation, residue from forest fires, and agricultural buildup) and belowground biomass, litter, and soil. However, a large part of it returns to the atmosphere via automatic and heterotrophic respirations (Baishya et al. 2009; Chhabra et al. 2002; Hernández-Guzmán et al. 2019; Reddy 1994; Schultz 2002). There is a need to conserve and enhance forest areas in order to encounter the emission targets (Lubowski et al. 2006). Forests play a crucial role in mitigating and adapting to climate change. Forests are considered one of the biggest sinks, reservoirs of carbon in terrestrial ecosystems. According to Global Forest Resource Assessment Report 2015 by the Food and Agriculture Organization

(FAO), the worlds' forests store an estimated 296 Gt of carbon in both AGB and BGB accounting for almost half of the total carbon stored in forests, the other half being the SOC. Globally, an overall decrease of 17.4 Gt of carbon stored in forest biomass has been observed in the past 25 years, accounting for 2.5 Gt of carbon dioxide (FSI 2019).

IPCC in 2003 released good practices guidance, dividing the five pools of carbon stored in forest ecosystem aboveground biomass (AGB) and belowground biomass (BGB) (categorized as living portion of biomass) and dead wood and litter contributing as dead organic matter. And the fifth pool is soil organic matter (SOC) individually accounting for nearly 50% of total carbon locked in forests. Several factors affect the carbon capture process like tree age, photosynthetic efficiency, and leaf area (Chavan and Rasal 2011) along with density and distribution of trees in the forest (Babbar et al. 2021). Therefore due to the higher net production, tropical forests have the greatest capacity for carbon sequestration (Brown and Lugo 1992; Chhabra and Dadhwal 2004; Sedjo and Sohngen 2012). Numerous studies stated that the old trees sequester a large amount of carbon (Brown and Lugo 1992; Fang et al. 2014; Gratani et al. 2016; Hernández-Guzmán et al. 2019; Lubowski et al. 2006; Luyssaert et al. 2008; Pechanec et al. 2018), while many types of research argue as the tree matures, their carbon sequestration capacity declines over time (Sohngen and Mendelsohn 2003; Terakunpisut et al. 2007). Sohngen (2003) had introduced the two most significant factors in carbon sequestration which are land use-land cover change dynamics. Decreasing deforestation and increasing afforestation activities are vital measures for the tropical regions, whereas afforestation is important in temperate regions (Sohngen 2003).

Forest land conversion to other land use types for agricultural and urban development: forest degradation through fuelwood extraction and local livestock grazing in the forest and deforestation have historically been major precursors of greenhouse gases (IPCC 2006; Sahana et al., 2018; Lorenz and Lal 2010). Therefore, the concept of urban greenery has gained huge popularity where the administration has implemented strategies to maintain the urban green spaces and plant more trees in order to mitigate climate change effects (Velasco et al. 2016). UNFCCC has worked on an extensive range of policy measures to highlight the issues of climate change mitigation where GHG inventories from all the emission sectors of the country are being shared by the participating country as a National Communication (NATCOM) (FSI 2019). Millennium Ecosystem Assessment in 2005 emphasized measuring and mapping the ecosystem services which will help policymakers, stakeholders, and environmentalists (Fisher et al. 2009). Numerous programs like Clean Development Mechanism by UNFCCC, REDD+, and Green India Mission have been initiated at international as well as national level to enhance forest carbon therefore reversing the effects of climate change (Adams et al. 2018; Dai et al. 2015). Using growing stock volume equations for assessing AGB and harvest sampling method for the BGB are some of the conventional methods for evaluating the carbon stocks in a forest area (Forest 2017; Lal and Singh 2000; Meena et al. 2019). Conversely, the use of RS and GIS along with various models has also been used widely for assessing carbon sequestration (Adams et al. 2018; He et al. 2016). Where a process-based Dynamic Land Ecosystem Model (DLEM) (Zhang et al. 2012) has been used to stimulate SOC and vegetation carbon storage. Carbon Exchange by the Vegetation-Soil-Atmosphere System (CEVSA) model, Geo-Process Model-Based Ecosystem Photosynthesis Theory (GEOPRO), and Carnegie Ames Stanford Application (CASA) productivity model along with other light use efficiency models were being used in China to assess the vegetation carbon pool by means of vegetation net primary productivity as a variable (Gao and Liu 2008; He et al. 2016). Similar kinds of studies have been carried out to encounter the impact of land use expansion and urban expansion on the ecosystem services of carbon sequestration rate using the InVEST (Integrated Valuation of Ecosystem Services and Trade Offs) model in Pakistan and Beijing in the year 2017 and 2015, respectively (Chen et al. 2017; He et al. 2016). Thus, the current research sought to measure the carbon stock and sequestration using the InVEST model, which is one of the key determinants of climate change. There are various methods to determine the carbon content using LULC data, for example, the IPCC provides standard equations for the calculation of the carbon stock captured and its associated gain or loss in any class of LULC. In a LULC change, a forest area remains in the same class, or it gets converted into some other class; the associated carbon change can be detected using IPCC equations. The IPCC equations require a lot of data generation, extensive field work, and heavy lab work which is not possible for the present study because of the large study area (IPCC 2000). So, we selected the InVEST model for the carbon stock detection using remote sensing techniques. IPCC supports the use of remote sensing for the detection of LULC changes, and similar goes with the carbon stock detection associated with these LULC changes. It is a prerequisite and a novel attempt to assist support in creating a stronger policy plan for managing the urban ecosystems in the face of global climate change and accelerated urbanization (Mallick et al., 2021). The government of Delhi has been consistently making efforts in improving the forest cover of Delhi and is taking initiatives under the schemes like National Mission for a Green India, Green Budget, National Afforestation Programme scheme, and Forest Fire Prevention and Management Scheme for forest conservation and management. There are more than 41 city forests being developed by the Delhi government in the past 15 years which would not only help in improving the water harvesting capacity of the forest but will also increase the carbon potential of the forest. There is very limited research on the carbon stocks of Delhi, and our study is the first initiative to calculate the carbon potential of the green cover of Delhi. The present study carried out a geospatial assessment of carbon sequestration along with the economic value in the National Capital Territory (NCT) of Delhi. The objectives of this study are, *first*, land use/land cover assessment and its analysis; *second*, carbon sequestration calculation and economic valuation; and *third*, potential suggestions in the context of the present study analysis.

2.2 Study Area

The NCT of Delhi is the world's second-largest city located in northern India between the latitudes of 28° 12′ and 28°53′ North latitude and longitudes of 76°50′ and 77°23′ East (Fig. 2.1). Delhi has an area of 1483 km^2. The geography of Delhi primarily contains three categories: the plains, the ridge, and the Yamuna plains (Sinha et al. 2014).

Delhi falls under the semi-arid zone type of biogeographic classification (Rodgers and Panwar 1988). According to the Planning Commission of India (1985–1990), based on the physiography and climate, Delhi falls under the category of Trans-Gangetic Plain Region in agroclimatic zones (MoEF and Kalpavriksh 2004). The NCT of Delhi acts as a transition zone between two contrasting ecosystems. It is influenced by the semi-arid and arid desert of the west and the fertile Gangetic plains of the east. Thus, it harbors features of both these biogeographic zones. The geography of Delhi can be physically divided into three segments: the Ridge, the Yamuna flood plains, and the plains. Much of the Delhi area is plains. Delhi has an increasing built-up area about of 36.67%, 15.8% forest area, and 33.92% agricultural area (Chakraborty et al., 2021).

According to the Department of Forest and Wildlife, Delhi, the NCT has 139.12 km^2 of recorded forest area. It covers the Delhi Ridge, Asola Bhatti Wildlife Sanctuary, 26 protected forests, 42 City forests, and 12 other forests. Some of the native trees of ridge are *Acacia nilotica*, *A. modesta*, *A. catechu*, *A. senegal*, *Anogeissus pendula*, *Acacia leucophloea*, *Butea monosperma*, *Salvadora persica*, *Holarrhena antidysenterica*, *Cordia dichotoma*, and *Ziziphus mauritiana*. Exotic vegetation at the ridge includes the dominant introduced *Prosopis juliflora* (a hardy Mexican species introduced in 1878), and this has completely dominated the local vegetation in Delhi. According to the National Bureau of Soil Survey and Land Use Planning of the Indian Council for Agricultural Research, Delhi has alluvial soil type (MoEF and Kalpavriksh 2004).

2.3 Database and Methodology

To measure the carbon sequestration in the NCT of Delhi region, the succeeding steps are followed. Land use/land cover maps for the year 2000 and 2020 have been prepared using Landsat and Sentinel satellite data which is attained from United States Geological Survey (USGS) Earth Explorer official website. LULC analyses and maps for the years 2000 and 2020 have been used to prepare the carbon potential maps using InVEST model, calculating the increase or decrease in the various carbon pools along with its economic evaluation over the years.

The use of RS and GIS is an integral and reliable method for the collection of data stand-alone applications using maps and ecosystem production function to produce the results in biophysical and economic terms (Babbar et al. 2021). These

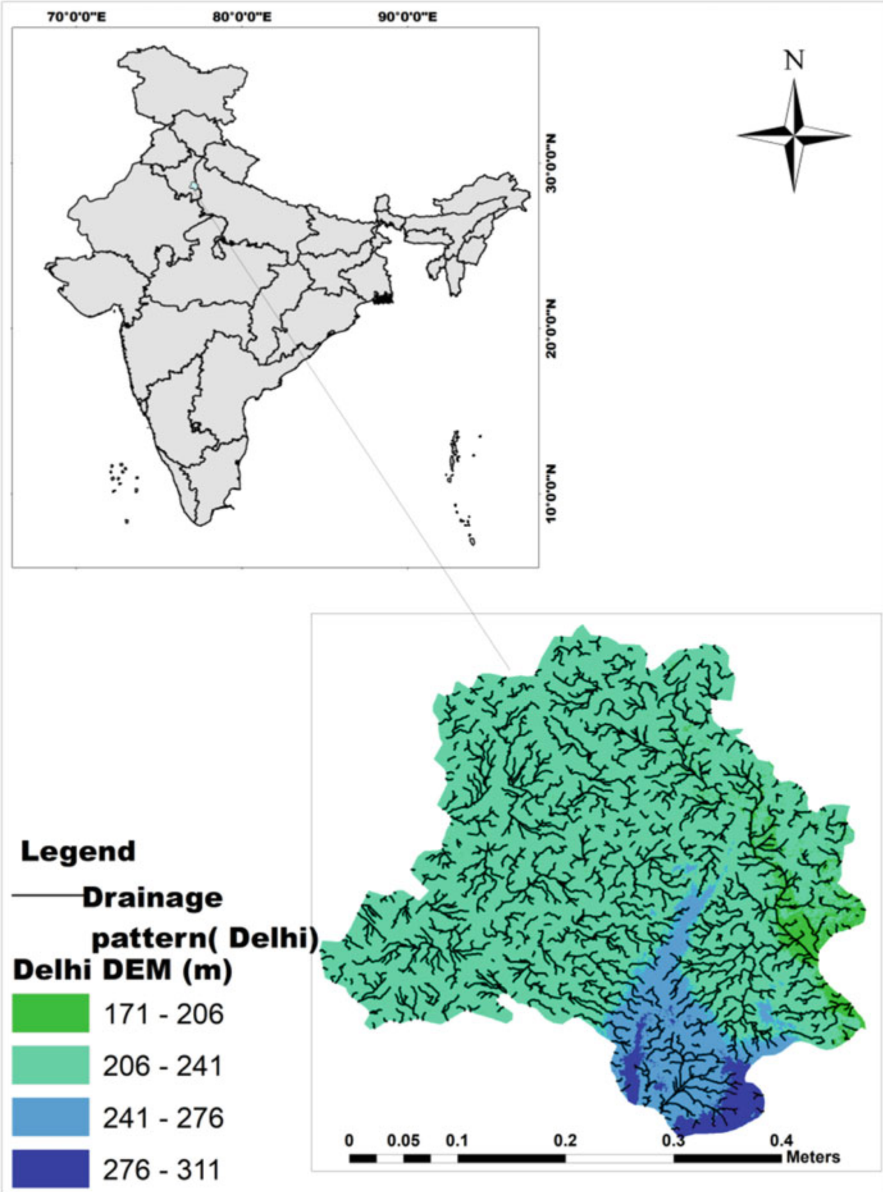

Fig. 2.1 Location map of NCT Delhi, India

technologies are cost-effective tools for mapping any change occurring over extended period of time (Coppin and Bauer 1996). Land use and land cover are an empirical approach for understanding the anthropogenic and environmental interactions (Prakasam 2010).

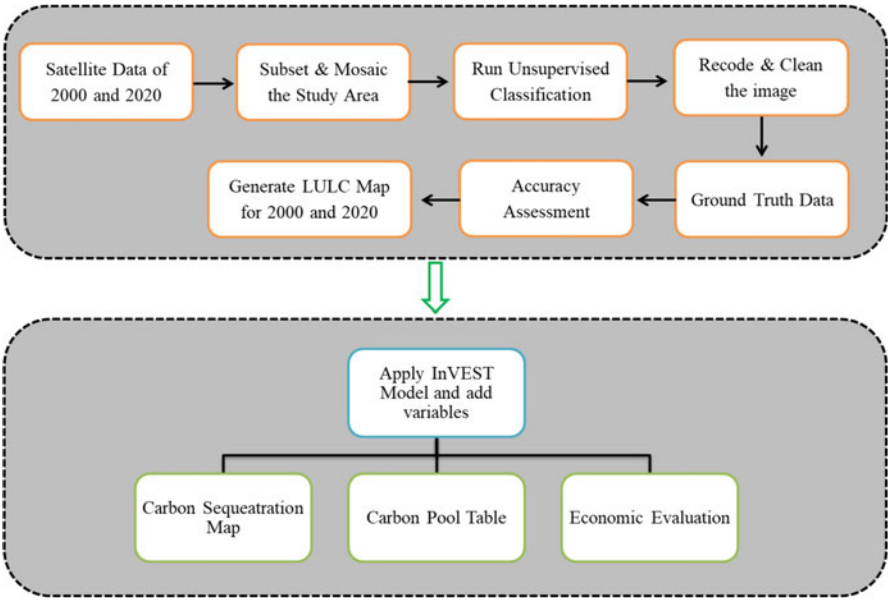

Fig. 2.2- Methodological framework of the study

The InVEST model is developed by the Natural Capital Project, Stanford University, which aims to capitalize the natural assets and transform the decision-making policy. The InVEST model uses the LULC maps along with the carbon stock variables, i.e., soil organic carbon (SOC), belowground biomass (BGB), aboveground biomass (AGB), and dead organic matter (DOM), to quantify the existing carbon stock in the land and estimate the sequestered carbon for the respective period of time. The yearly rate of change and a discount rate can be used to calculate the market worth of sequestered carbon. The detailed methodological framework to develop this study is given in Fig. 2.2.

The study addresses the following questions: (i) how much carbon it can sustain; (ii) how variations in LULC cover influenced the forest's carbon sequestration capability; and (iii) how much fixed carbon increase/decrease has happened through time.

2.3.1 Preparation of Land Use-Land Cover Map

The Landsat and Sentinel data for the years 2000 and 2020 were used to prepare the LULC map for the NCT region of Delhi (Table 2.1). Pre-processing of the image was performed using Erdas imagine software which included layer stacking, geo-referencing, creating subset, and mosaic.

Table 2.1 List of satellite database used in the study

Satellite name	Data type	Details of the data	Period
Landsat 5 (Thematic Mapper)	Spatial data (30 m resolution)	Path/Row 146/40	February 2000
Sentinel-2A	Spatial data (10 m resolution)	Path/Row 146/40147/40	October 2020, December 2020

For the preparation of LULC, unsupervised classification was run, and the spectral classes were grouped into 85 classes which were later converted into ten classes. Features like scrubland and open forest and agricultural land and parks show similar spectral signatures, which were recoded followed by the cleaning process. Google Earth Pro was also used to investigate the accuracy of classes while recoding. Accuracy assessment was performed for the years 2000 and 2020 by using Google Earth Pro, as the ground-truthing was not conducted because of the Covid-19 pandemic. Kappa statistics, user's accuracy, and producer's accuracy were generated for the LULC map (Rahaman et al., 2019). After generating LULC maps for the respective years, statistical changes were calculated to determine the change detection and change matrix over the period of time.

2.3.2 *Generation of Carbon Sequestration Map Using InVEST Model*

The land use and land cover maps prepared for the year 2000 and 2020 have been used as baseline information for preparing the carbon sequestration map using InVEST model. Using the LULC maps, the model produces the following results: (i) the amount of carbon stored in various carbon reservoirs, (ii) the total volume of carbon in a landscape over time, and (iii) an estimate of the remaining stock's market value of sequestered carbon.

A carbon pool data was generated for the classes using the FSI report published by the Ministry of Environment and Forest assessment for the state of Delhi. For the non-forest classes, IPCC 2006 guidelines methodology for determining GHG inventories in the AFOLU (Agriculture, Forestry, and Other Land use) Sector was followed (Table 2.2). To evaluate the economic value of sequestration, the monetary value of each carbon unit, discount rate, and the change in value of carbon sequestered over time, i.e., annual rate. Discount rates are the standard economic financial discounts including economic inflation over a time period which can be negative or positive. A market discount of 3% was added, the economic value derived from social cost of CO_2 ¼ 55 of a sequestered ton of carbon, i.e., $201.85 and the yearly rate of change in carbon price is considered zero (Babbar et al. 2021).

Table 2.2 Carbon pool inputs for InVEST model

Sl. no	LULC class name	AGB	BGB	SOC	DOM
1	Trees outside forest	24.41	5.02	71.17	2.14
2	Dense forest	44.6	17.5	47.28	2.53
3	Open forest	10.68	4.19	29.07	1.71
4	Agricultural land	3	2	8	1
5	Fallow land	1	1	10	0
6	Waterbodies	0	0	0	0
7	Settlements	2	1	5	0
8	Openland/scrubland	8	8	25	3
9	Grassland/parks	6	6	20	2
10	Roads	0	0	0	0

Note: AGB Aboveground biomass, BGB belowground biomass, SOC soil organic carbon, DOM dead organic matter

2.3.3 Accuracy Assessment

Accuracy assessment is an integral part of the classification process with a goal to quantify the efficiency of grouping pixels into the featured class. Accuracy assessment was performed using random sampling where the minimum number of observations placed in each class was 30 with at least overall 350 observations. Accuracy assessment was performed using Google Earth Pro software for both years. Kappa statistics determines the precision of the accuracy of classification. It is an efficient method to analyze a single error matrix as well as to compare the difference in various error matrices. Kappa coefficient ranges from -1 to 1; a value closer to 1 indicates more accurate results. Producer's accuracy measures the error of omission; and the user's accuracy measures the error of omission; this shows how well real-world land cover types can be classified.

2.4 Results

2.4.1 LULC Assessment

Ten LULC classes were acknowledged in the NCT of Delhi region, namely, dense forest, open forest, tree outside forest, agricultural area, fallow land, scrub land, parks waterbodies, roads and settlements for both the years are shown in Fig. 2.3. The spatial distribution pattern of the LULC map is being summarized in Table 2.3. A difference in area between the years 2000 and 2020 indicates a change, with a negative number indicating a reduction and a positive value indicating an increase in the area. During the period 2000–2020, there was a growth in trees outside forest, dense forest, open forest, settlements, and roads, which may be attributed to better management practices by the forest department as well as increased anthropogenic

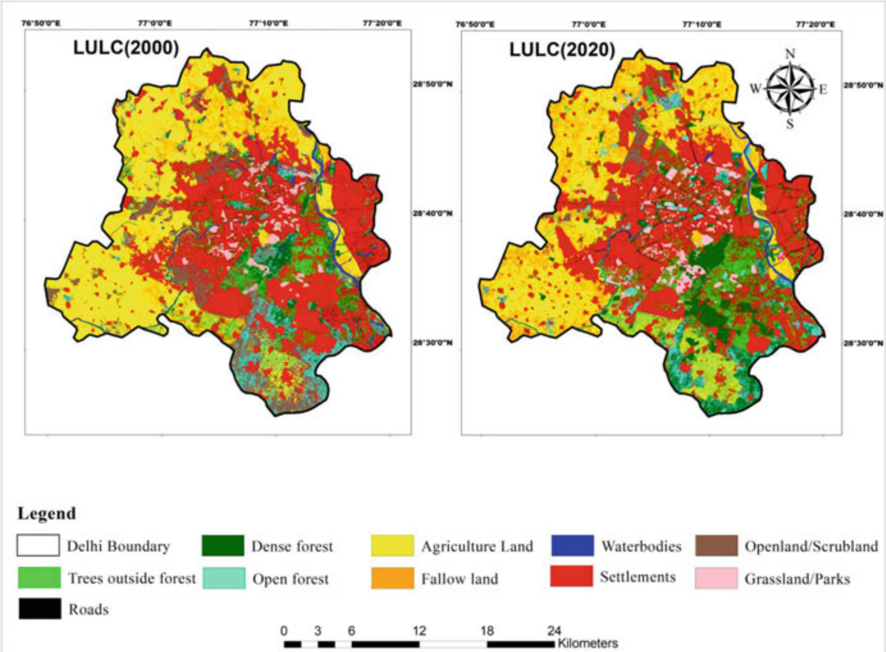

Fig. 2.3 LULC maps for the years 2000 and 2020

Table 2.3 Land use land cover change over the period

Class	Year 2000		Year 2020		Change 2000–2020	
	Area in Ha	Area in %	Area in Ha	Area in %	Area in Ha	Area in %
Trees outside forest	11917.9	7.92	15511.9	10.32	3594	2.40
Dense forest	6717.24	4.46	11488.8	7.64	4771.56	3.18
Open forest	6467.58	4.30	6523.08	4.34	55.5	0.04
Agricultural land	42471.4	28.21	29365.5	19.53	−13105.9	−8.68
Fallow land	12675.3	8.42	21630.2	14.39	8954.9	5.97
Waterbodies	2370.15	1.57	1754.78	1.167	−615.37	−0.41
Settlements	46671.6	31.00	51083.7	33.98	4412.1	2.97
Openland/ scrubland	16548.6	10.99	2733.44	1.82	−13815.16	−9.17
Grasslands/parks	1771.83	1.18	6213.96	4.13	4442.13	2.96
Roads	2926.8	1.94	4049.45	2.69	1122.65	0.75

pressure. From 17.86% in 2000 to 26.43% in 2020, there has been a total increase of 2.40% in trees out of forest cover, 3.18% in dense forest, and 2.96% in parks and gardens, bringing the entire green canopy of Delhi to 26.43% in 2020. The area of aquatic bodies has shrunk by 0.41%, possibly owing to encroachment. Settlements increased by 2.97% and roads by 0.75% due to the expansion of urban area as well as the developing suburbs. Jain et al. (2016) also cited a significant development in the built-up area and transportation network of roughly 13–15% from the twentieth century to 2006.

After 2006, there was a steep decline in the developing built-up area, reaching as low as the growth rate of 1.83% up till 2014. Anthropogenic factors were a key factor in the reduction of Delhi's green cover in the twentieth century. Ahmad in 2020 also stressed the need for growing rural development in impacting Delhi's vulnerable environment (Ahmad 2020). It was in the early twenty-first century that Delhi faced the harsh reality of reduced tree cover, which accounted for up to 10% of the city's total area. Afforestation programs were organized by the government to meet the criteria of National Forest Policy, 1988 which stipulated that one third of the total geographical area on the plains need to have tree cover in order to ensure ecological sustainability. Scrubland has seen a significant decline of 9.17%, owing to urbanization and numerous government organizations' planting efforts. There is a significant disparity between agricultural and fallow land, which is attributable to the month of the selected satellite images, which highlights the difference in sowing and harvesting times, resulting in a variance in the areas. However, there has been an overall decrease of 4151 ha in the agricultural area.

In Table 2.4, the LULC map change matrix distinctively indicates the transition between the LULC classes over the time period between 2000 and 2020. It demonstrates how areas are converted from one class to another. The table's highlighted diagonal axis represents the areas that have remained unchanged over time. Major transitions in forest areas, scrubland, fallow land, parks, and waterbodies are depicted in the table. The conversion of 383 ha of open forest into dense forest has resulted in an increase in dense forest area, while some waterbodies, such as ponds, have dried up in the forest area and are covered with vegetation. Around 750 ha of

Table 2.4 LULC matrix for the year 2000 and 2020

		LULC area in ha (2020)										
	CLASS NAME	**Agriculture land**	**Dense forest**	**Fallow land**	**Parks**	**Open forest**	**Openland/ Scrubland**	**Roads**	**Settlement**	**Trees outside forest**	**Water bodies**	**Grand Total**
LULC area in ha (2000)	**Agriculture land**	20554.74	561.86	13922.61	284.63	499.69	946.19	131.36	4125.83	1644.87	172.23	42844.02
	Dense Forest	34.43	2668.93	40.65	382.65	383.30	17.24	117.62	342.88	623.34	110.39	4721.43
	Fallow land	5004.80	241.21	3751.50	150.96	260.65	481.27	57.80	1704.17	730.68	98.04	12481.07
	Grassland/Park	341.20	339.39	211.77	2450.35	192.68	41.77	88.05	898.03	453.68	36.50	5053.41
	Open Forest	323.83	2942.22	242.06	152.99	1316.99	84.72	87.61	595.99	347.79	43.09	6137.28
	Openland/Scrubland	1328.89	2910.84	1857.44	1271.75	2430.74	577.78	239.69	3993.03	1718.62	112.12	16440.90
	Roads	13.71	32.80	33.04	40.36	51.15	15.38	198.99	1601.67	265.83	25.75	2278.68
	Settlements	849.02	896.20	838.42	850.25	750.32	284.98	2306.29	34737.09	6593.24	318.81	48424.60
	Trees Outside Forest	852.39	759.09	654.65	489.64	459.87	135.05	526.26	3121.54	2782.71	189.80	9970.99
	Water bodies	128.12	190.56	131.90	52.15	181.64	29.48	65.79	284.49	213.81	709.20	1987.13
	Grand Total	**29431.12**	**11543.10**	**21684.03**	**6125.72**	**6527.02**	**2613.85**	**3819.46**	**51404.71**	**15374.56**	**1815.93**	**150339.50**

open forest have also been encroached upon in order to make way for settlements. Due to the rapid growth of the population, a large portion, i.e., around 4125 ha of agricultural and 1704 ha of fallow land, as well as small sections of park has been transformed into communities. On the one hand, scrubland has been decreased through tree planting to boost green cover and turn sections into forest land and parks, but on the contrary, settlements have taken over a substantial section of the land. A negative relationship can be observed in the agricultural area, built-up area, and wasteland. The economy of Delhi began to migrate from the primary to the tertiary sectors in the early twenty-first century, necessitating a change in the LULC pattern. This resulted to the sprawling of new as well as existing colonies into the agricultural and open land areas (Jain et al. 2016). Tree planted on the outskirts of agricultural and fallow land regions has also enhanced tree cover outside of forests. Many waterbodies outside the forest have been dried up, and many of them have been transformed into settlements. Waterbodies are diminishing significantly as a result of discharge of domestic sewage and other industrial effluents leading to the reduction of water body capacity as well as degrading water quality. One of the key causes of significantly reduced areas of waterbodies through time has been decreasing rainfall, which has led to receding ground water levels. Changes in meteorological and climatic conditions have a massive impact on cropping patterns, resulting in increased soil salinity and sodicity, as well as degraded and starving farmland in the NCT of Delhi. It turned kharif season croplands into uncultivated fallow lands (Suzanchi and Kaur 2011).

2.4.2 Accuracy Assessment of LULC Maps

The accuracy of the LULC map of 2000 and 2020 was assessed using the most commonly used kappa accuracy evaluation method. Landsat 5 (TM) and Sentinel-2A high-resolution satellite images were used to conduct the assessment. Overall classification accuracy for the year 2000 is 91.21%, with kappa = 0.9022. Overall classification accuracy for 2020 is 94.53%, with kappa = 0.9393. This demonstrates that the LULC map for the year 2020 is more precise than the LULC map for the year 2000. Individual producer and user accuracy for all classes is also shown in Table 2.5 and Table 2.6 for the respective years to support the kappa statistics.

2.4.3 Assessment of Total Carbon Stored and Total Carbon Sequestration

Total Carbon Analysis: The quantity of carbon being stored in Mg in each grid cell in a landscape is known as total carbon. It is the total of the four carbon pools, i.e., AGB, BGB, SOC, and DOM, linked with the LULC classes delineated in the map (Table 2.7). The map indicates the forest cover containing 0.456–1.119 Mg of

Table 2.5 Accuracy assessment of LULC for the year 2000

Class name	Conditional kappa for each category	Producers' accuracy (%)	Users' accuracy (%)
Trees outside forest	0.8238	100.00	83.87
Dense forest	0.9272	82.86	93.55
Open forest	0.8888	87.10	90.00
Agriculture land	0.9321	93.94	93.94
Fallow land	0.9282	93.55	93.55
Waterbodies	0.8904	100.00	90.00
Settlements	0.9666	89.19	97.06
Openland/ scrubland	0.8927	93.33	90.32
Grassland/parks	0.925	82.35	93.33
Roads	0.8337	95.65	84.62
Overall classification accuracy = 91.21%			
Overall kappa statistics = 0.9022			

Table 2.6 Accuracy assessment of LULC for the year 2020

Class name	Conditional kappa for each category	Producer's accuracy (%)	User's accuracy (%)
Trees outside forest	0.8587	100.00	87.10
Dense forest	0.8925	90.32	90.32
Open forest	0.9281	90.63	93.55
Agriculture land	1	100.00	100.00
Fallow land	1	96.97	100.00
Waterbodies	0.9631	96.67	96.67
Settlements	0.9344	100.00	94.12
Openland/ scrubland	0.9628	90.63	96.67
Parks	0.9627	87.88	96.67
Roads	0.8897	93.10	90.00
Overall classification accuracy = 94.53%			
Overall kappa statistics = 0.9393			

carbon in each grid cell. The green cover outside the forest contains less amount carbon, i.e., 0.136–0.456 Mg for the agricultural and fallow land and 0–0.136 for the built-up area. Total carbon stored in the current scenario, i.e., 2020, is 45×10^5 Mg, which includes all the LULC classes, i.e., forest area, cropland, tree outside forest, parks, scrubland, and settlements. Forests and trees outside of forests generate 64% of the total carbon stock; agriculture and fallow land store 13%, while settlements comprise 8.9%. As it can be observed from the map, the value for carbon stock in each grid cell is the same for both years. This is due to change in LULC, that the total carbon amount differs, thus resulting in an increase of 8.5×10^5 Mg.

Table 2.7 Statistics of total carbon (Mg) stored in the years 2000 and 2020

Sl. no.	Class name	Area (in m^2)	Carbon (Mg) in each class (2000)	Area (in m^2)	Carbon (Mg) in each class (2020)
1	Trees outside forest	102792600.00	551501.4769	155,234,900	1594883.363
2	Dense forest	47304000.00	664366.2046	114,917,000	1286036.147
3	Open forest	62038800.00	280586.3003	65,303,200	298109.108
4	Agriculture land	425184290.00	532034.8169	294,299,580	412019.44
5	Fallow land	128715300.00	419262.0239	216,563,200	259875.84
6	Waterbodies	20124900.00	0	18,258,100	0
7	Settlements	476534690.00	960119.165	510,704,380	408563.52
8	Openland/scrubland	164078100.00	68269.36	26,312,500	115,775
9	Parks	50801400.00	252276.6579	61,488,600	209061.24
10	Roads	27809100.00	0	40,466,300	0
	Total carbon stored		3728416.005		4584323.658

Delhi forest cover consists of 1.7×10^4 Mg of carbon stored in the present times which have increased by 3.2% as compared to the stored carbon in the year 2000. The Delhi forest is classified as a dry deciduous and thorn forest, with middle storey thorny trees dominating the landscape and open areas scattered throughout. In 2019, the carbon allocation in the forest area for the north and central ridge forest regions was calculated as follows: AGB (40–49%) > SOC (29.93–37.7%) > BGB (20–-22%) > Litter (0.27–0.59%) (Meena et al. 2019). According to FSI, Delhi's forest (together with TOF patches of >1 ha size) has stored 1.2 million tons of carbon, which is distributed among the following carbon pools: SOC (0.84 m tons) > AGB (0.28 m tons) > BGB (0.098 m tons) > Litter (0.021 m tons) > Dead wood (0.002 m tons) (FSI, 2019).

Sequestered Carbon Analysis: The carbon sequestered during the period from 2000 to 2020 is presented as Mg/grid in the map (Fig. 2.4 and Table 2.8). The positive and negative values indicate the sequestration of carbon and loss in the atmosphere, respectively. The sequestration is exclusively displayed by the dense forest, open forest, and scrubland (Fig. 2.5). The total amount of carbon sequestered is 6.9×10^5 Mg to which forest accounts for 6.8×10^5 Mg, whereas carbon emission accounts for 10.3×10^5 Mg.

Net Present Value: The net present value map represents the monetary value of carbon sequestered in the NCT region of Delhi in currency ($) units per pixel where carbon sequestrations is described by positive values and carbon emission by negative values (Fig. 2.6). The total net present value of sequestered carbon from 2000 to 2020 is $ 106 million.

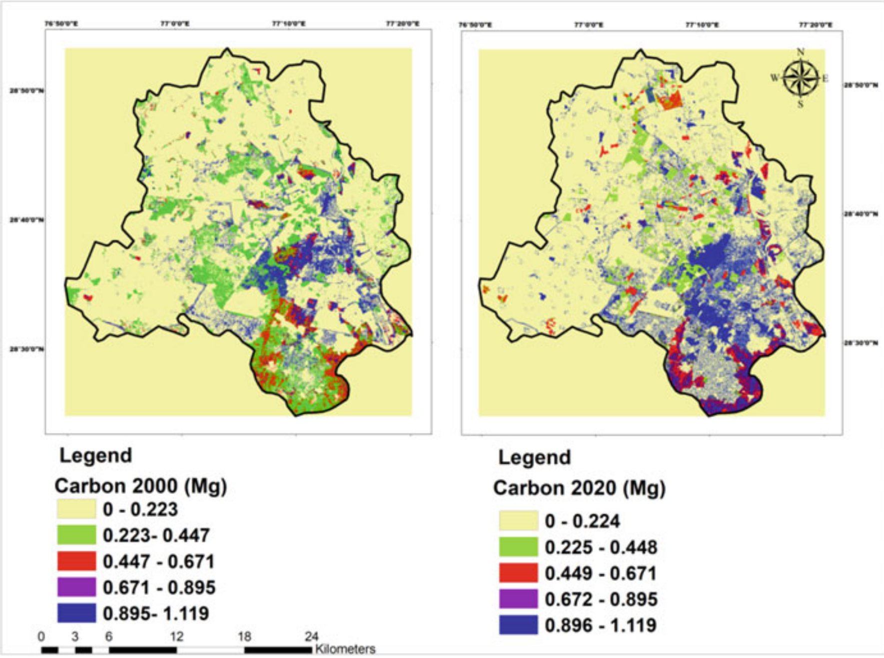

Fig. 2.4 Map showing stored carbon (Mg) in the years 2000 and 2020

Table 2.8 Statistics of carbon sequestration in the years 2000 and 2020

Sl. no.	Class name	Carbon sequestration in each class (2000–2020)
1	Trees outside forest	1043381.886
2	Dense forest	621669.9424
3	Open forest	17522.80766
4	Agriculture land	−120015.3769
5	Fallow land	−159386.1839
6	Waterbodies	−47532.77238
7	Settlements	−551555.645
8	Openland/scrubland	47505.64
9	Parks	−43215.41785
10	Roads	−113229.5634
	Total carbon sequestered	695145.3164

2.5 Discussion

The increasing rate of carbon dioxide emission is primarily due to the burning fossil fuel, land use change pattern, and deforestation (Raupach 2008; Canadell et al. 2007; Solomon et al. 2009), which has been identified as one of the major sources of changing Earth's energy balance (Shine and Sturges 2007) causing global surface

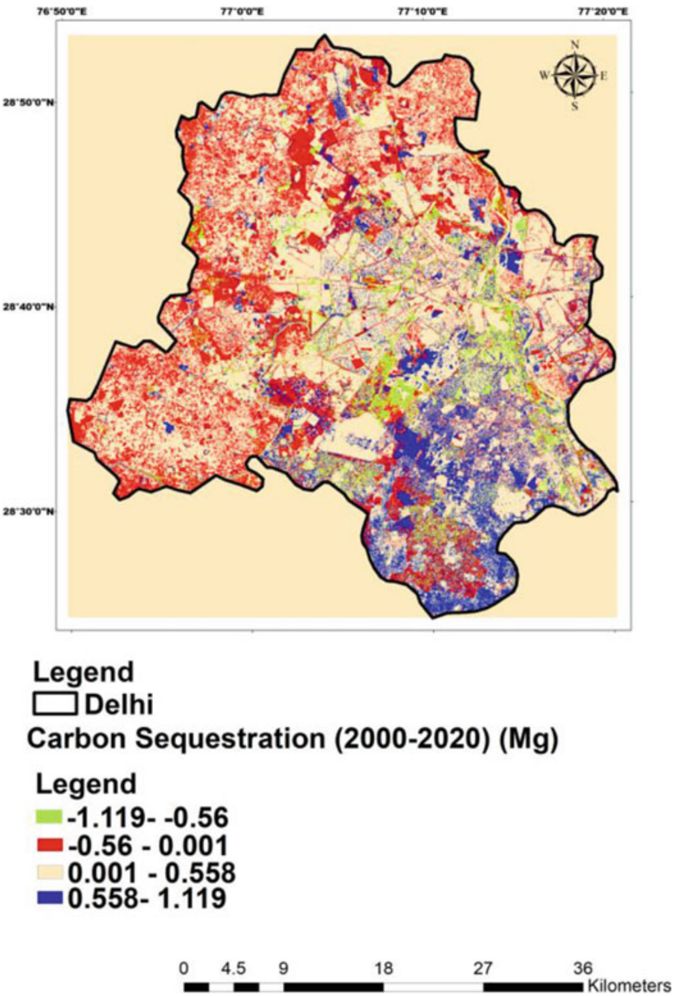

Fig. 2.5 Carbon sequestration (Mg) map from the years 2000 and 2020 in the NCT Delhi green cover region

warming or abrupt climate change (ACC) (Allen et al. 2006). The carbon sequestration function provided by forests is critical for the well-being of human society and of planet Earth. Conversely, ACC endangers forestry sinks affecting the carbon exchange (Waring and Running 2007; Houghton et al. 2001) and stabilization process (Schulze 2006), therefore releasing more CO_2 in the atmosphere.

It has been proven that substantial reductions in emissions result in extremely modest rates of temperature (Lowe et al. 2009), whereas forest management including avoiding deforestation, reforestation, and afforestation on non-forested land can decrease the rising atmospheric CO_2 (Pacala and Socolow 2004). Particularly, BGB and detritus carbon are more important sinks of carbon than aboveground to stabilize the carbon cycle (Lal 2004; Barker et al. 2007; Kintisch 2009).

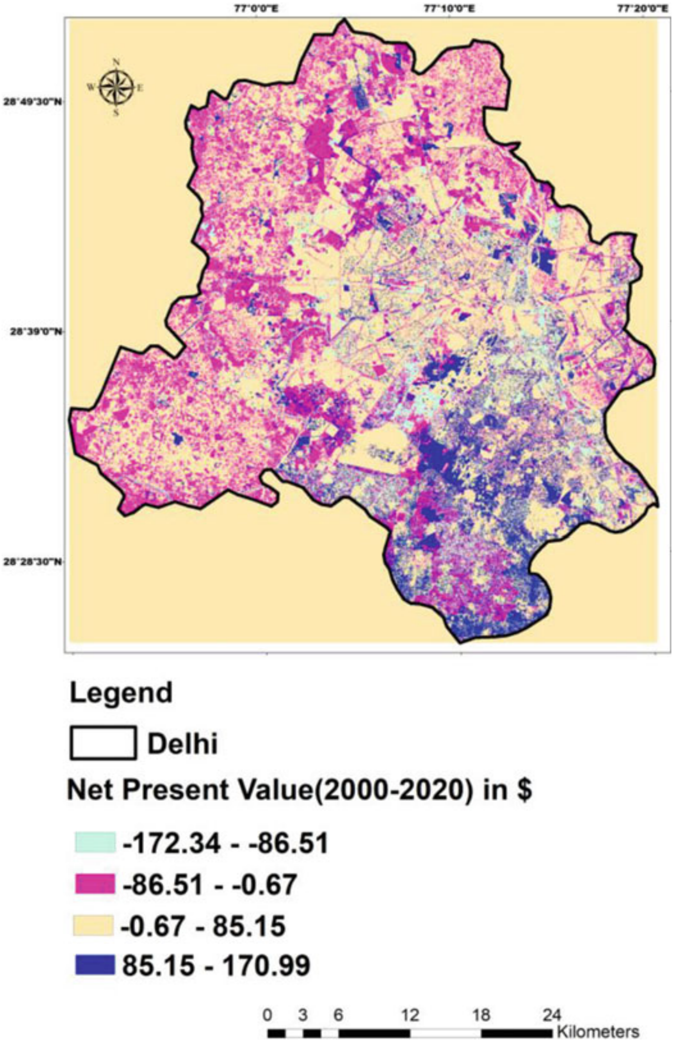

Fig. 2.6 Net present value ($) map for the years 2000 and 2020

Thus, it is important to study the present ecosystem trajectory as well as the history to evaluate the potential carbon storage (Zhao et al. 2019; Lubowski et al. 2006). There is a research gap, whether forests that have over time been through environmental changes are capable of dealing with the current ACC (Valladares 2008). In the paper, we assess the carbon storage and carbon sequestration in the NCT Delhi over a period of 2000–2020 using the InVEST model. The influence of changes in LULC on the various geographic carbon pools throughout time is also underlined in the chapter. Moreover, the economic evaluation of the sequestered carbon as well as the carbon emission indicates the carbon reduction comprehending the revenues.

As the world is urbanizing, urban area development, and linear infrastructures development is increasing day by day which affects the natural area very adversely (Pathak et al. 2020) and subsequently the biodiversity of that area also gets disturbed (Rousta et al. 2018). It also affects the ecosystem services of the area altering the geomorphology and vegetation of the area. The results of the present study reveal that with continuous expansion of built-up area, green cover can also grow simultaneously leading to a considerable carbon stock gain, positively attributing to the urban carbon dynamics. There has been a substantial amount of increase in the forest cover as well as the tree outside forest area which has resulted in an increase in carbon stock from the previous year. The Hon‘ble Supreme Court of India directed the protection of ridge through various orders, and Master Plan of Delhi, 2001 stated the protection of ridge in its pristine form. Since 1997, Annual Greening Action Plan was prepared by Forest Department to undertake afforestation programs in cooperation with various government agencies and civil society groups, and there has been a tremendous increase in the green cover of Delhi. From conserving the forest area and planting in the open patches' areas of recorded forest, the Forest Department has also developed 40 New City forest with a total area of 1603 ha in 2007 to 2010. A total of 17 lakh plantations were raised in the sanctuary from 2001 to 2013.

Studies show that Delhi's forest ecosystem has more capacity to store carbon (Meena et al. 2019). To enhance the carbon sequestration capacity of the green spaces, tree species composition which directly affects the biomass hence impacting the overall forest carbon stock is important (Yang et al. 2005; Borah et al. 2015; Solomon et al. 2017). In Delhi, around 40% of the forest land has been invaded by an exotic species *Prosopis juliflora*, which not only invades the home species but also reduces the water levels of the area. Therefore, native vegetation species should be given consideration during forest management policymaking; it not only increases the forest productivity but also affects the carbon stock (Meena et al. 2016).

Although there has been an increase in the carbon stock of Delhi on the contrary, there has also been an increase in carbon emission/loss in the atmosphere as a result of urban infrastructure development, growing fragmentation in the natural area, and climate change impacts such as declining temperature and rainfall patterns (Dhali et al., 2019). Forests have been subjected to anthropogenic disturbance like deforestation, encroachment, overgrazing, resource exploitation, urbanization, and exotic plantation which has fragmented the forest areas and has altered the forest structure and species composition which has impacted the carbon stock of the forest (Sinha et al. 2014). The agriculture industry, on the other hand, has been strongly affected by the change in LULC, with significant regional environmental effects. The other factor is that development in the NCT of Delhi has been disproportionate (NCRPB 2005). According to a similar research conducted in Guang'an, the city's ecology has a concentric ring distribution in the metropolis, carbon emission zone at its core, the second zone of carbon potential, and the third zone is the established carbon storage (Li et al. 2017). Similarly, Seoul experienced a tremendous urban expansion in the late twentieth century with little contemplation of natural area resulting in increased fragmentation of natural landscapes and decreasing carbon sequestration (Han et al. 2018).

Calthorpe and Ryn (Calthorpe and Ryn 1986), a well-known urban planning professor, put it succinctly: "Sustainability" means finding an equilibrium between the economic, social, and natural environments to make them coexist indefinitely. Forming equilibrium in the urban infrastructure and green space is a crucial strategy to improve carbon sequestration in the urban ecosystem. Land use changes in the early 1920s resulted in a 140 Pg C loss from the terrestrial biosphere, with deforestation accounting for 20% and fossil fuel combustion accounting for 80% of the total (Denman et al. 2007). As a result, it is critical for LULC policies to enhance the ecological land cover pattern in cities in order to maintain a stable carbon cycle. In addition, implementing de-carbonization in the global economy will cut carbon emissions, therefore minimizing the consequences of climate change in the immediate future.

An economic evaluation of the intangible ecosystem services brings in the consideration of common man along with the policymakers about the importance of natural resources (Areendran et al. 2020; De Groot et al. 2012; Sugandh and Joshi 2018; Gratani et al. 2016). Spatiotemporal data not only provide information to policymaker and forest management officials about the immediate protection required area to utilize the funds effectively but also provides data on historical changes in the landscape which might help the management team in mapping the loopholes of degradation and therefore effectively planning the action required. This information not only prevents the funds to be used in arbitrary ways but also makes the actions cost-effective.

2.6 Conclusions

The present study attempts to measure the carbon storage as well as the sequestration of the green cover at a regional scale based on the land use-land cover map during 2000–2020 in the NCT of Delhi, exhibiting the carbon potential of urban forest ecosystem of Delhi. Multi-temporal satellite data was used to detect the carbon gain and loss over the period of time. Results reveal that the total carbon storage capacity has increased by 18.67% during the year 2000–2020, with the increase in forest area and tree outside forest. A significant decrease in scrubland which is being converted to open forest area has been observed, where the agricultural land and fallow land have also faced a decline in the area. The carbon sequestration capacity of the region is 6.9×10^5 Mg which unveils the high amount of carbon emission, i.e., 10.3×10^5 Mg. The net present value of the carbon stored and sequestered in the system is $106 million. These findings insight the urban dynamics and the landscape changes responsible for the conservation and restoration of the natural area of Delhi. The findings not only confer the carbon sequestration values but also insights the details of changing LULC patterns and its effects on various resources which are of importance in the future policymaking and green infrastructure development. This study provides a baseline data for developing carbon stock infrastructure, REDD+ scenario generation, NDC, and climate change calculations, providing more accurate data and loopholes of the studies. Whereas the monetary value of carbon sequestration brings into account about the importance of natural habitats in urban areas providing a tangible approach to stakeholders in managing intangible resources. However, the model used includes an oversimplified carbon cycle providing proportional changes in the carbon sequestration and uses projected market prices. Moreover, it overlooks the photosynthetic activity, type of soil, microbial activities, and nutrient availability which are considered important parameters for calculating carbon stock (Song et al. 2016; Gupta et al. 2017). Additionally, the study has not calculated any prediction to highlight the factor affecting forest management like the increasing anthropogenic pressure of the growing population in Delhi.

The research conducted provides a database to stakeholders and policymakers and further raises questions about the maximum potential of Delhi green infrastructure to store carbon stock. On the basis of the current study inference, the authors would like to recommend increasing the plantation activities in the open forest as well as the scrubland via reforestation and afforestation. Agroforestry can also be practiced on the agricultural area and fallow land which would not only improve the soil profile of the area but will also help in improving the water table of Delhi. For better forest management practices, deforestation for fuelwood usage should be banned, and alternative renewable sources should be used. The increase in forest cover will not only increase the carbon stock but will also sequester the atmospheric carbon dioxide reducing the carbon emissions which will also help in achieving the Nationally Determined Contributions targets.

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Chapter 3
Assessments of Bio-physical Characteristics of Vegetation Cover in Western Part of Purulia District in West Bengal

Shyamal Dutta and Soumen Chatterjee

Abstract Biodiversity is an innate possession of a nation as it necessitates not only safeguarding of single or multiple species but also the habitat as a sum total with its surroundings. Proper documentation of biodiversity facilitates conservation of natural resources of any nation which needed assessment of its biophysical properties in different orders and of different scales. Forests are the most precious global ecosystems providing provisions to biodiversity as well as to the rural communities inhabited in or around the forest boundaries across the countries. But these resources are subjected to continuous deterioration due to human activities summing up with climate change. Assessment of bio-physical properties of vegetation cover under any forest jurisdiction enables the conservation plan formulation for future outcome. The present study includes the type of assessment of biophysical characteristics which includes vegetation type with canopy cover (CC), biological richness (BR), disturbances (DI), and fragmentation (FI) along with climatic and fluvial characteristics as a growth factor under a single frame for the western part of the Rarh plateau in West Bengal which administratively belongs to Purulia District. These regions have most dense forest cover with high biological richness with less amount of disturbance by human activities. Geospatial tools in terms of satellite images provide base of the assessment in the present study which includes formulation of different forest quality zones with in a large spatial extent. This may become a useful tool for formulation of conservation plan in the study area and areas with the same biological characteristics.

Keywords Biodiversity · Biological richness · Disturbance index · Fragmentation index · Forest quality

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3.1 Introduction

It can be stated with certainty that biodiversity matters because it is the storehouse of all the resources on which we depend upon (Cresswell and Murphy 2016). Among all the resources, a nation possesses biodiversity provides most important and essential services for the overall functioning of the life support system of the earth (Morton and Hill 2014). Biodiversity can be identified on various levels like gene, species, and ecosystem, and each have their own role in protecting the environment, stabilizing the ecosystem, and providing the basic services without which human survival may be put into risk (Anguela et al. 2010; Kornelsen and Coulibaly 2013; Bertoldi et al. 2014; Fang and Lakshmi 2014). Forests are the most precious terrestrial ecosystem that account for more than 30% of the earth's land surface and provide some of the richest of all habitats, offering food and shelters for various species (Rao and Pant 2001; Díaz et al. 2006; Kurnar 2011). Geographically, forest cover is found to be distributed unevenly over the globe; hence, some part of the globe are endowed with greater forest cover with stable ecosystem, while other parts have paucity of forest with fragile ecosystem (Sahana et al., 2016). Forests provide several ecological, economic, and social function to life like cycling of water and nutrient, conservation of soil, regulation of greenhouse gas, supplies fodder and timber, etc. (Kurnar 2011; Wang et al. 2019) They have also enormous ecological importance as the root structure holds the soil particles tight checking them from erosion, regulate the extremity of temperature and rainfall pattern, mitigate global warming by absorbing emission, and so on (Chatterjee 2021). Above all, vegetation acts as biodiversity repositories (Li and Wu 2004; Cumming 2007) endowed with timber and various NTFPs which include herbs and medicinal resources as well as fuelwood.

It is an established fact that biodiversity is under tremendous threat of extinction, fragmentation, and disturbance in global or regional scale due to changing climate and human interference (IUCN 2017). The WWF (2017a, b) has estimated that about 13 million hectares of forests are being degraded every year and 50% of the global natural forests have been vanished. According to Ghosh (2018), India has nearly 24% forest cover of its total geographical area. Degradation of natural forest may raise the concentration of CO_2 (Vitousek 1994; Arevalo et al. 2009; Calle et al. 2016). Changing climatic regime has also posed most important intimidation to the functionality of forest resources (Sonwa et al. 2012; Vitousek 1994; Meshesha et al. 2014). The unscientific as well as irreversible changes in land cover mainly under the head of extension of built-up area and encroachment of agriculture land are considered to be the major reasons for the decrease in forest cover (Ghosh et al. 2021). Hence, proper documentation of biodiversity including the status of vegetative cover is extremely important for the conservation of natural resources of any nation which needed assessment of its biophysical properties in different orders and of different scales (Fensholt 2004; Malik et al. 2019). Assessment of bio-physical properties of vegetation cover enables the conservation plan formulation for future outcome. Pokhriyal et al. (2020) considered the initiative of SFR (sustainable forest management) as a crucial element for conservation of biodiversity as it is plugged with several problems like human interference, irregularity in climate elements, and substantial wildfires. Wildfires may decrease forest productivity, their implications on climate found to have last long (Gauthier et al. 2015).

To assess forest vulnerability and susceptibility in regional and the overall biophysical cover in general, several methods have been used across the globe which include computer-based logical model, data assemblage, indicator-based analysis, bioclimatic as well as equilibrium models, etc. In Yellow River delta, the fuzzy logic model has been incorporated to identify, for example, ecological vulnerability (Wu et al. 2018) as this model helps reduce the uncertainty in the decision-making process. Forest fire data and meteorological variables have been used by Thorne et al. (2018) to assess the vulnerability of forest cover of the southwest of the USA. Analytic Hierarchy Process (AHP) is habitually referred to as the Saaty's method which is an admired and extensively worn method to assemble a matrix expressing the relative standards of a group of attributes (Coyle 2004). First of all, pairwise comparisons are calculated for all factors to be employed in the calculation. The next step is to calculate a list of the relative weights of each variable considered for the study, and finally a standard matrix has been calculated to fabricate an overall vector which provides the response we seek according to the relative qualities.

The present study includes the type of assessment of biophysical characteristics which includes vegetation type with canopy cover (CC), biological richness (BR), disturbances (DI), and fragmentation (FI) along with climatic and fluvial characteristics as a growth factor under a single frame for the western part of the Purulia District in West Bengal. These regions have most dense forest cover with high biological richness. This area is mostly composed of hilly tract with virgin and forest which has been less disturbed by human activities (Mandal et al. 2018a). Various government reports (Census Handbook, Human Development Report for Puruliya) have noted that this area comprises of several backward community development blocks with larger portion of the inhabitants belonging to the tribal group. They are mostly depending on forest products for their livelihood (Mandal et al. 2018b). Introduction of several developmental projects (like establishment of Purulia Pumped Storage Project at Bagmundi) at the cost of forest land not only destabilizes the forest-based ecosystem but also puts the livelihood of the inhabitants into the verge of destruction (Chakrabarty and Chatterjee 2010). Increasing population in the recent year is also considered to be aggravating the situation (Ghosh et al. 2021). All these factors have a cumulative impact on the biophysical environment that needs to be properly addressed. There is no such type of work that has been carried out in regional scale in the Eastern part of the country and also in the case of West Bengal which can give emphasis on micro-level analysis of forest quality in the sub-district level. Hence, an attempt has been made in the present study to assess the present biophysical characteristics of the study area which contains several blocks with diverse physical identity and to formulate different forest quality zones within a large spatial extent by implying geospatial tool. This may become a useful tool for formulation of conservation plan to policymakers at the regional level in the study area and areas with the same biological characteristics.

3.2 Methods and Database

Assessment of bio-physical quality is done using basic indicator approach in the present study which is accommodating in shaping the quality of vegetation using a set of appropriate indicators and also in decision-making for policy implementation (Table 3.1). Six indices including biological richness (BR), disturbance index (DI), and fragmentation Index (FI) from biological characteristics of the region and rainfall, temperature, and drainage density from the physical setup have been used to scrutinize the quality of vegetation in the western part of Purulia district (Figs. 3.2 and 3.3). LISS III satellite data of IRS obtained on 2005 and 2006, respectively, with 1:50,000 scale provide the three main spatial indicators, namely, biological richness, fragmentation index, and disturbance index (Dutta et al., 2017; Roy et al. 2012). In this source, different landscape level parameters (e.g., patchiness, interspersal, porousness, biotic disruption, buffer, and juxtaposition with human establishment)

Table 3.1 Description and source of data used in the study

Themes	Indicators	Source of data	Class character as defined by source of data	Ranges of class value as defined by source
Biological features	Biological richness (BR)	Indian Institute of Remote Sensing (*IIRS*)	Low	1–33
			Moderate	34–49
			High	50–69
			Very high	> 69
	Disturbance index (DI)		Low	11–18
			Medium	19–24
			High	25–28
			Very high	>28
	Fragmentation index (FI)		Low	1
			Medium	2
			High	> 2
Physical Features	Average annual rainfall (based on quartiles)	SWAT and CRU websites from 1901–2018 (*Swat: CRU:*	Low	1617.7–1896.6
			Medium	1896.7–2138
			High	2138.1–2331.1
			Very high	> 2331.1
	Average annual temperature (based on quartiles)		Low	25.1–25.3
			Medium	25.4–25.5
			High	25.6–25.8
			Very high	>25.8
	Drainage density	SRTM 30 m. USGS	Low	1
			Medium	2
			High	3
			Very high	4–5

have been judiciously measured to find out disturbance index. Impact of anthropogenic activities on the forest resources coupled with the forest ecosystems capacity in the face of varying environment circumstance has been more specifically identified with the help of disturbance index and biological richness (Thakur et al. 2020). Fragmentation has been computed as the ratio between the quantity of forest and non-forest patches per unit area which has been graded into low, medium, and high ranging from 1 to 37 where 1 is assigned for low fragmentation, 2 for medium-level fragmentation, and the rest of the values (3–37) for high-level fragmentation. Disturbance index and biological richness are prepared by the following formulas:

$$\mathrm{DI} = \int \mathrm{fragmentation,\ patchiness,\ interspersion,\ porosity,\ biotic\ disturbance\ buffer,\ and\ juxtaposition}$$

$$\mathrm{BR} = \sum_{\mathrm{i}=1}^{\mathrm{n}} \mathrm{DI_i} \times \mathrm{Wt_{i1}} + \mathrm{TC_{ji}} \times \mathrm{Wt_{i2}} + \mathrm{SR_i} \times \mathrm{Wt_{i3}} + \mathrm{BV_i} \times \mathrm{Wt_{i4}} + \mathrm{EU_i} \times \mathrm{Wt_{i5}} \tag{3.1}$$

where BR and DI refer to biological richness and disturbance index, SR reflects the richness of species, BV denotes biodiversity value, EU refers to uniqueness of ecosystem, and Wt refers to weights of the respective parameters.

Climatic data in terms of temperature and rainfall of different stations has been collected from SWAT and CRU websites (*Swat: , CRU:*. After calculating station-wise annual average temperature and rainfall, inverse distance weighted (IDW) interpolation has been used under GIS platform to prepare spatial outlook of rainfall and temperature in the study area. Drainage line has been extracted from SRTM-DEM with 30 m of spatial resolution extracted from USGS Earth Explorer, and density of drainage in the study region has been prepared in GIS platform by Arc Map 10.2.1 software.

Bio-physical characteristics of vegetation cover in the study region have been identified by synthesizing the six thematic layers utilizing the analytical hierarchy process (AHP). Following the scale of weight in AHP procedure postulated by Saaty (1980 and 2008), de Jong (1984), each raster layer has been reclassified which includes biological features of the region, i.e., biological richness, fragmentation index, and disturbance index, as well as physical features, i.e., mean rainfall per annum, mean temperature per annum, and drainage density (Areendran et al., 2020). A summed-up explanation of weights and their indicators are presented in Table 3.1. AHP aids in criteria evaluation and effective decision-making procedure by reducing the uncertainty of the analysis by on conditions that preeminent way out by the using decisive indicators. Certain value for a particular parameter has been assigned in the AHP model in response to association of the pairwise matrix (Table 3.2). The process started with the computation of pairwise matrix for all the indicators employed in the study by adding all the columns in the matrix. To reduce subjectivity, normalized pairwise matrix has been calculated by averaging all elements in

Table 3.2 Pairwise comparison matrix of six variables (Source: Based on analytical hierarchy process (AHP)

Class	Biological richness (BR)	Disturbance index (DI)	Fragmentation index (FI)	Rainfall in mm.	Temperature in °C	Drainage density (meters/km)
Biological richness (BR)	1	0.143	0.166	5	5	4
Disturbance index (DI)	7	1	2	0.166	0.25	0.2
Fragmentation index (FI)	6	0.5	1	0.2	0.25	0.2
Rainfall in mm.	0.2	6	5	1	3	0.25
Temperature in °C	0.2	4	4	0.333	1	0.25
Drainage density (meters/km)	0.25	5	5	4	4	1

AHP scale: 1 equal importance, 3 moderate, 5 strong importance, 7 very strong importance; 2, 4, 6, 8 intermediate values; 1/3, 1/5, 1/7 values of inverse comparison rows. Individual criteria weight can be obtained by this process. Then, row averages have been used to identify the priority vector (Table 3.3). In the next step, consistency ratio has been calculated to check the accuracy of calculated value. Eventually, computation of weighted sum matrix has been performed jointly with the linear additive model to compute vegetation quality. It should be noted that to make the final output more rational, consistency ratio has been calculated by dividing the CI with tabulated random number Pourghasemi et al. (2012). It will reflect the statistical acceptability of the final output.

$$\text{Consistency Index(CI)} = \lambda_{\max} - 1/n - 1 \tag{3.2}$$

$$\text{Consistency Ratio(CR)} = \text{Consistency index(CI)}/\text{Random Index(RI)} \tag{3.3}$$

3.2.1 Study Area

The study area belongs to the westernmost part of the district of Purulia of West Bengal and lies between 23°N and 23°30′N latitude and 85°30′ E and 86°30′ E longitude (Fig. 3.1), which is mainly demarcated by streams and hills and tropical deciduous forest. It's surrounded by the state Jharkhand in three sides, on the north side with Hazaribagh and Dhanbad, on the southern side by *Singbhum* district of Jharkhand, Paschim Medinipur and Bankura districts on the eastern side, and Ranchi on the western side. Administratively, the study area covers the Blocks of Jhalda I and II, Barabazar, Jaipur, Arsha, Bagmundi, Purulia I, and Balarampur.

The forest divisions coupled with physiography of the study region are under the plateau region of Chotonagpur upland chiefly composed of rolling land. Degradation of land has been considered to be very active and quite evident in this region as whole area is intercepted with isolated hills and dissected plateau with narrow valley of different rills and gullies indicates. Ajodhya hilly region is the highest elevated tract in this region with a peak having elevation of 677 meters. Besides this Bagmundi ranges also have an average altitude of 300 meters. The twin rivers of Kangsabati and Subarnarekha with their tributaries dissected the whole region. As per agroclimatic classification of the state, this study region falls under undulating lateritic terrain in the western part of West Bengal. As per Champion's classification, Purulia division of forest mainly comprised of tropical dry deciduous forest category which mainly contains coppice Sal forest mixed with misc. species like *Palash*, *Kusum*, *Mahua*, *Neem*, and *Kend* (Champion and Seth 1968). Overall, these forest reserves have immense ecological values as it contained 74 varieties of trees, 59 types of shrubs, at least 23 types of climbers, and 27 varieties of bamboo species. Last but not the least, plants with medicinal values of nearly 100 species, namely, Aswagandha, *Satmuli*, *Vrigoraj*, *Haritaki*, *Amla*, *Bahera*, *Karanj*, *Neem*, etc., enrich the species variety of this forest. All these products are the major source for timber, non-timber produces, firewood, and medicinal plant to neighboring communities.

Table 3.3 Normalized pairwise comparison matrix of six variables (Source: Based on analytical hierarchy process (AHP))

Class	Biological richness (BR)	Disturbance index (DI)	Fragmentation index (FI)	Rainfall in mm.	Temperature in °C	Drainage density (meters/km)	Sum	Criteria weight
Biological richness (BR)	0.068	0.009	0.010	0.467	0.370	0.678	1.602	0.267
Disturbance index (DI)	0.478	0.060	0.117	0.016	0.019	0.034	0.722	0.120
Fragmentation index (FI)	0.410	0.030	0.058	0.019	0.019	0.034	0.569	0.095
Rainfall in mm.	0.014	0.361	0.291	0.093	0.222	0.042	1.023	0.171
Temperature in °C	0.014	0.240	0.233	0.031	0.074	0.042	0.635	0.106
Drainage density (meters/km)	0.017	0.300	0.291	0.374	0.296	0.169	1.448	0.241

Random index for six samples is 1.24 which is greater than the result of 1.18 λ max value 13.395; consistency index (CI) 1.471; consistency ratio (CR) 1.186

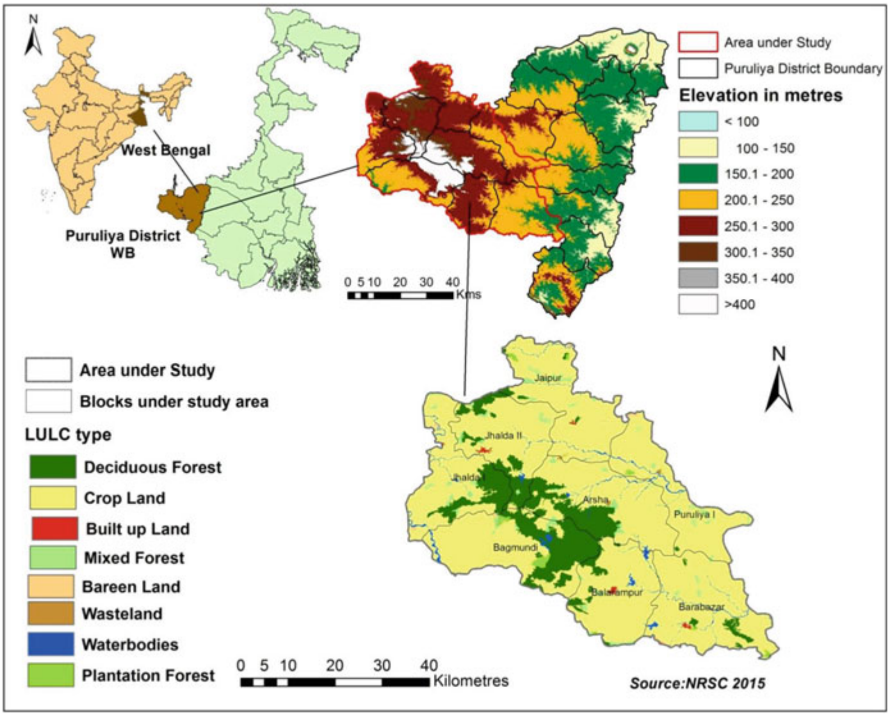

Fig. 3.1 Location of the study area

3.3 Results and Discussion

3.3.1 Biological Features of the Study Area

The spatial indicators of biological characteristics prevailing in the study region have been identified using three basic parameters, namely, biological richness (BR), disturbance index (DI), and fragmentation index (FI), which have been collected from satellite data of IRS LISS III (Fig. 3.2). Here we considered biological richness as a function of ecosystem distinctiveness, species luxury, and biodiversity values, terrain intricacy, and disturbances and depicts the potential for harboring highest number of ecologically unique and important species (NRSC 2008). According to criteria set by IIRS (2012), biological richness ranges between 23 and 200 which has been classified into four classes, i.e., low (23–33), medium (34–49), high (50–69), and very high (>69), in the study area. Moderate and high level of biological richness is very rare in the study area which contains only 15% of the total region, whereas low level of richness has been distributed in the south-central hill area (Ajodhya Hill region). The rest of the area fall under very high (82% of the total area) richness of vegetation species and high biodiversity values.

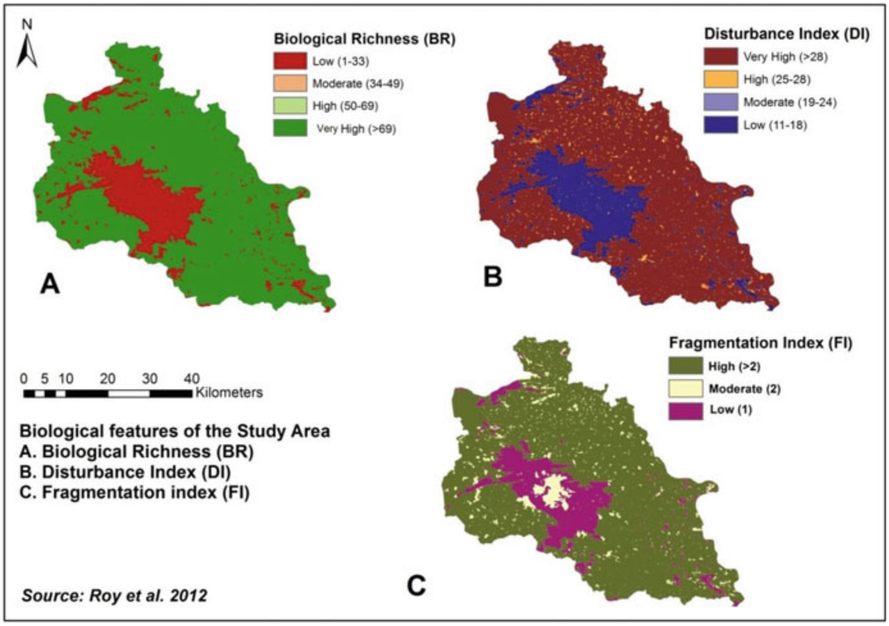

Fig. 3.2 Landscape-level biological features of the study area: (**a**) biological richness (BR), (**b**) fragmentation index (FI), (**c**) disturbance index (DI)

Fragmentation has been formulated as the ratio of forest and non-forest quantity of land per unit area. Different landscape parameters like fragmentation, patchiness, interspersion, porosity, human disturbance buffer, and human establishment buffer are considered to find out the disturbance index. Human activities having adverse effect to any natural resources or anthropogenic interference on the landscape are considered as a discrete experience on specific and continuous time which modifies cumulatively overall landscape associated with ecosystem, community and population structure, and availability of resources (White and Pickett 1985). Fragmentation of forest ecosystem is everywhere in the area except the Ajodhya hill region. Hilly region is least impacted with human interference and contains less population and settlement pressure. About 86% of the total area of the study region is under high level of fragmentation in forest ecosystem.

Dynamics of climatic and physico-social environmental condition and impact of anthropogenic activities on forest resources have been assessed with the help of disturbance index and biological richness (Thakur et al. 2020). Disturbances on forest ecosystem are very rare in and around Ajodhya hill region which contains low and medium categories (13.7% to total area) depicting that the region with low biological richness and low fragmentation has low disturbances in terms of anthropogenic activities. High level of disturbances is found in 4.3% of the total area under study and distributed in a dispersed manner. More than 82% of the area is under high level of threat in term of disturbance index.

3.3.2 Physical Features of the Study Area

Differentiation in slope and diversity in terrain elevation lead to variability in different climatic conditions, humidity, temperature, and rainfall, as well as edaphic factors, soil type, color, depth, and texture, which cumulatively influence the growth and development of vegetation (Sinha et al. 2018). From physical environment, temperature, rainfall, and drainage density, i.e., spacing of drainage network within specific area, are three basic constituents which play a significant role behind growth of vegetation. The climatic condition which prevail over the district of Purulia is basically of hot sub-tropical type. Summer months are considerably hot with average temperature over 40 °C, and winter months are somewhat colder with average temperature of 10 °C. Most of the areas in the district experience exceptionally high evaporation with scanty rainfall which causes dryness of surface water bodies and soil moisture. Majority of the precipitation of the study area has been contributed by the southwestern monsoon wind during late summer. Annually, the region receives 1100–1500 mm of rainfall. In the study area, the maximum annual rainfall recorded is 2985.5 mm, whereas minimum recorded is 1617.67 mm. There is a sharp declining 25.8 ° trend of yearly rainfall found over the region in west to east direction. Annual average temperature trend also follows the same pattern where maximum temperature touches 25.8 °C and minimum temperature touches 25.01 °C. Overall, the drainage density of the study area is high as numerous first-order streams have been originated from the hilly rugged terrain mainly from the Ajodhya Hill region and its surroundings, which ultimately developed a well-structured drainage pattern in the study area (Fig. 3.3).

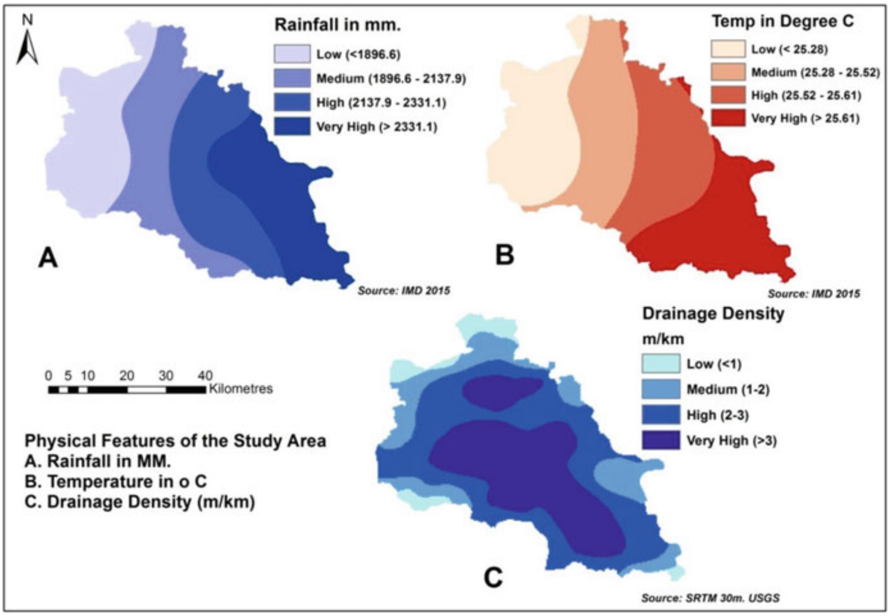

Fig. 3.3 Physical features of the study area: (**a**) rainfall, (**b**) temperature, (**c**) drainage density

3.3.3 Discussion

3.3.3.1 Bio-physical Characteristics of the Vegetation Cover of the Study Area

Multi-criteria analysis is a diverse data-oriented analysis process and decision-making method which uses a set of attributes that has a tangible expressive value and a quantifiable quality of audit, including inter-unit associations. Bio-physical characteristics have been identified by utilizing the analytical hierarchy process (AHP) in the study area with derived weights generated for all raster layers mainly from biological features of the region, i.e., biological richness, fragmentation index, and disturbance index, as well as from physical features, i.e., rainfall, temperature, and drainage density (Saaty 2008). Overall analysis shows that only 12.6% of the total area is categorized under high-quality vegetation cover followed by low-quality (20.3%) and medium-quality (67.1%) vegetation cover in the study area (Fig. 3.4). High-quality forest cover is found around the region adjoining to the Ajodhya hill and in the blocks of Bagmundi, Arsha, eastern part of Jhalda, and some parts of Barabazar in dispersed manners. Though these areas contain low-to-moderate level of biological richness, the fragmentation and disturbance are also very rare resulting into high-quality vegetation cover. Low-quality vegetation is found in the western-most part of the study area (western part of Jhalda I and II block) where fragmentation level and disturbances of green space are high. This region is also endowed with low level of rainfall and temperature which put hindrance against vegetation growth. Medium-level vegetation cover is found over the region under Jaipur, Purulia I, Arsha, and Balarampur. It is found that the vegetation quality map that high level of drainage density makes significant positive input behind high quality of vegetation in the study area.

Analysis of pairwise comparison matrix also discovered that all biological and physical indicators are prominent factors for inducing the bio-physical quality of vegetation in the study area (Tables 3.2 and 3.3). Consistency ratio (CR) has been computed for the matrix to understand the level of consistency achieved from weighting the indicators. Provided that the matrix weight has been randomly generated, the measure of CR yields an authentic value. But in the present work, consistency ratio (CR) 1.186 which is less than the random index values for six samples is 1.24 which make decision that the result the selection of the indicators with their association are very much relevance to identify the quality of vegetation of the study area (Table 3.4).

A large section of the population are dependent on climate-sensitive sectors like forest and grazing, agriculture, fisheries, etc. in India among which forests are considered a very critical ecosystem as well as vulnerable due to its high climatic dependency mainly in the state endowed with green space (Pokhriyal et al. 2020). Non-timber forest products (NTFP) not only have a greater contribution in the local economy of Purulia but are also indispensable for local communities. Our multi-criteria analyses revealed that more than 87% vegetation are under low-to-medium-

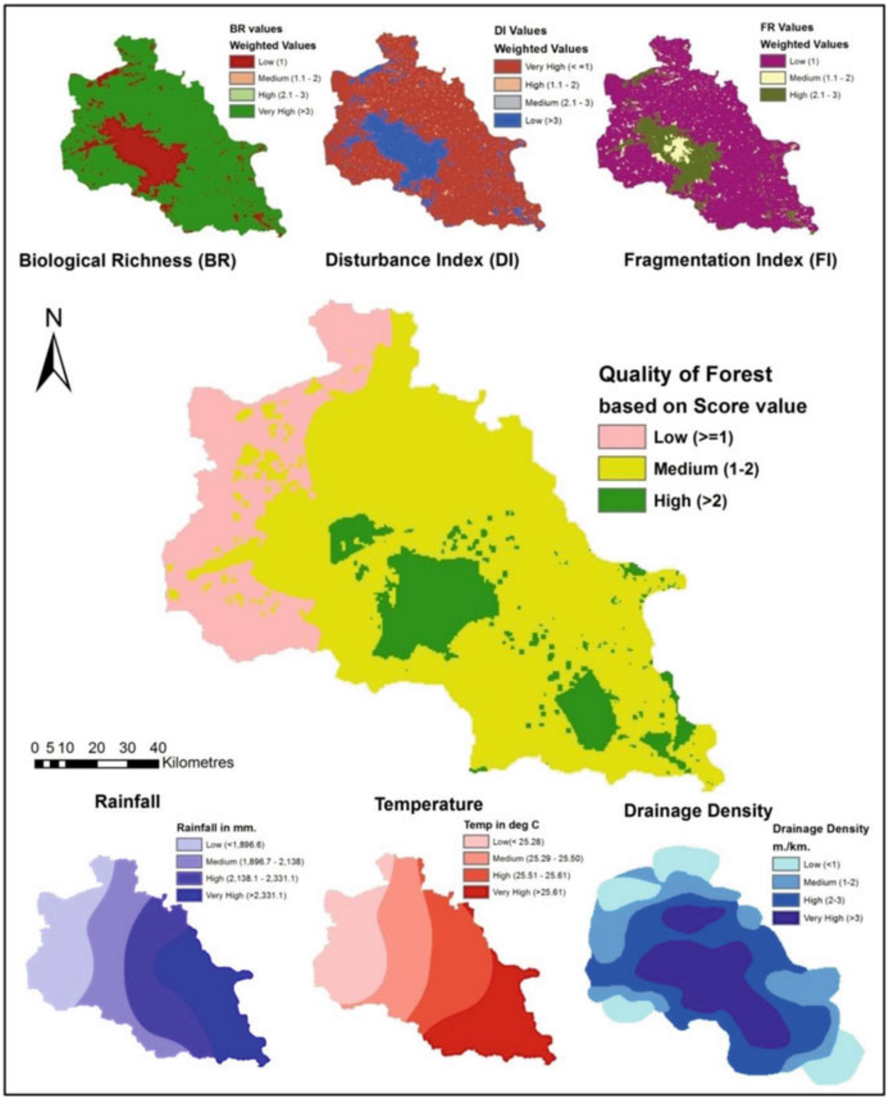

Fig. 3.4 Spatial distribution of vegetation quality in the study area based on AHP

quality vegetation cover, whereas only 12.6% vegetation is marked as high-quality vegetation cover. The main causes behind such degrading quality are less biological richness and species diversity, high forest disturbance in terms of human inference, and scanty average rainfall with high temperature (Pokhriyal et al., 2020). There are multiple determinants which control the quality of vegetation. Distribution structure and function of the vegetation patch are largely determined by the natural and anthropogenic disturbances, whereas climate parameter regime under specific annual

Table 3.4 Assigned and normalized weights of different features of thematic layers

Themes	Indicators	Source of data	Index	Weightage value
Biological Features	Biological richness (BR)	Indian Institute of Remote Sensing (IIRS)	Low	**1**
			Moderate	**3**
			High	**5**
			Very high	**7**
	Disturbance index (DI)		Low	**7**
			Medium	**5**
			High	**3**
			Very high	**1**
	Fragmentation index (FI)		Low	**5**
			Medium	**3**
			High	**1**
Physical Features	Average annual rainfall (based on quartiles)	SWAT and CRU websites from 1901–2018 (*Swat: CRU:*	Low	**1**
			Medium	**3**
			High	**5**
			Very high	**7**
	Average annual temperature (based on quartiles)		Low	**1**
			Medium	**3**
			High	**5**
			Very high	**7**
	Drainage density	SRTM 30 m. USGS	Low	**1**
			Medium	**3**
			High	**5**
			Very high	**7**

rainfall and temperature affect the spatial distribution of vegetation, and lastly the developmental activities affect the ecological attributes of the vegetation and their spatial distribution at a larger extent (Dolan et al. 2017; Dutta et al. (2021)).

3.4 Conclusion

Assessment of bio-physical properties of vegetation covers under any forest jurisdiction enables the conservation plan formulation for future outcome. The present investigation has been conducted to identify the forest quality based on biophysical variables in the western part of Purulia District of West Bengal which is the part of Rarh Plateau in Eastern India. Biological richness, fragmentation index, and disturbance index from biological characteristics and average annual rainfall and temperature with drainage density have been incorporated to assess the quality of vegetation of the study area under the most sophisticated multi-criteria decision-making process named analytical hierarchy process (AHP). From the assessment, it is clear that only 12.6% of the total area is categorized under high-quality vegetation cover which mainly concentrated in region adjoining to the Ajodhya hill and in the blocks of Bagmundi, Arsha, eastern part of Jhalda, and some parts of Barabazar in dispersed manners. Western part of Jhalda I and II block where fragmentation level and disturbances of green space is high, vegetation quality remain low (20.3%) and rest of the region containing the region under Jaipur, Purulia I, Arsha and Balarampur fall under medium quality vegetations status. It is found in the vegetation quality map that high level of drainage density makes significant positive input behind high quality of vegetation in the study area. Thus, degradation of vegetation quality in the study region is owing to human intervention and the diverse climatic condition mainly in the supply of rainfall. Efficient long-standing sustainable vegetation management policy is necessary to renovate and preserve the functioning of the green space. Efficient people's participation in management approach seems to be more potential in case of fragmented vegetated regions which includes afforestation, reducing in grazing, encroachment restriction which consider enhancing the sustainability of the forest in Purulia District. Local people engagement and participatory approach in forest conservation as well as uses of forest products may be effective in space-quality-specific forest patches under the area of study. In the present study, modern more efficient GIS-based multi-criteria decision-making process of analysis assists in recognizing the main areas of concern for the restitution and accomplishment of forest management policies. Outcomes of the present study will be informative and helpful for policymakers as well as regional stakeholders to acclimatize sustainable forest management strategies to control the advance forest degradation of this eco-sensitive region in the western part of West Bengal.

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Chapter 4
Delineating the Mangrove Patches Along Coastal Kerala Using Geographical Information System, Satellite Data and Field Validation

P. Pranav, N. Nandini Menon, U. Shameem, K. G. Mini, and Grinson George

Abstract Mangroves, wetlands and coral reefs are dynamic ecosystems that are easily affected by natural calamities as well as human interferences. The 2004 tsunami has served to improve awareness on the need to conserve and sustainably manage the mangroves. Therefore, mangrove areas are categorized as ecologically sensitive under the Indian coastal regulatory zone notification I (CRZ-I) in 2011. An accurate delineation of mangrove areas is important for its in situ conservation. Satellite remote sensing data and geographical information system (GIS) tools can be effectively used to define the boundary of mangrove patches. The advantages are that these are less expensive and less time-consuming than in situ sampling of individual patches. In the present study, we have used Google Earth Pro image search engine, Quantum GIS (Version QGIS 3.10) and SNAP (Sentinel Application Platform Version 8.0)—all open-source GIS softwares to map the distribution and features of mangrove areas. Cloud-free Sentinel-2 multispectral images (MSI) were acquired from the Copernicus data hub hosted by the European Space Agency (ESA). The pre-processing of satellite data and classification using the Random Forest (RF) method were carried out in SNAP and semi-automated classification using the maximum likelihood classification (MLC) method in QGIS. The pixel-based RF classification using Sentinel-2 satellite in SNAP showed the highest accuracy based on Cohen's kappa coefficient (K) among the three classification algorithms (RF ($K = 0.80$), MLC ($K = 0.68$) and K-nearest neighbour ($K = 0.61$) methods), followed by semi-automated classification in QGIS and Google Earth image-based classification. The pixel-based RF classification enables the fine classification of mangroves from other vegetation. These outputs are field verified with

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the ground control points (GCPs), collected during an extensive field survey along the coastal districts of Kerala. The successful methodology was employed to delineate the entire mangrove patches throughout the coastal regions of Kerala. This methodology can be adopted for mapping mangroves in the remaining coastal states of India to make an appropriate mangrove distribution library for India. This would help make a successful conservation plan to protect the diminishing mangrove forests in India. This book chapter highlights the utilization of advanced techniques in satellite remote sensing and GIS for better management of mangroves all across the globe.

Keywords Mangrove forests · Mapping · Conservation · Random forest classification · Sentinel-2 · QGIS

4.1 Introduction

4.1.1 Mangroves and Mapping

The sea level rise attributed to climate change is a serious concern to Indian coastal regions. The country has approximately 8129-km-long coastline with a coastal population of about 500 million (Swapna et al. 2020). Therefore, immediate attention has to be given to the protection of the coast and the people from the recently increasing natural disaster events that have been wreaking havoc on the coastal areas in the form of hurricanes and tsunamis. The coastal regions and wetlands are well assorted with features such as mangroves, seagrasses, sand dunes, salt marshes, coral reefs, etc. These ecologically sensitive ecosystems have a remarkable influence in regulating the impact of global climate change, as well as the socio-economic status and wellbeing of people especially those living in the coastal areas (Aye et al. 2019).

Mangroves are one of the most invaluable treasures distributed in the tropical and sub-tropical regions of the world. They have immense ecological and economic significance by harbouring diverse flora and fauna and by providing support to the livelihood of people who live on the coastline (Carugati et al. 2018). Climate change, modifications in the land use pattern and other negative anthropogenic activities create insecurity for the existence of mangroves in recent centuries. UN sustainable development goals (SDGs) 2021 particularly SDG-13, SDG-14 and SDG-15 are targeted to combat the effect of global warming and climate change by safeguarding nature and natural resources. Mangroves are one of the natural ecosystems that sequestrate around 24 million metric tonnes of atmospheric carbon dioxide per year, a critical component in fighting climate change (Ong et al. 1993).

In recent centuries, mangrove ecosystems are facing severe threats in various parts of the world (Kathiresan and Rajendran 2005). As per the Forest Information Service (FORIS) developed by FAO, there were about 19 million ha of mangroves in the world during the 1980s, which have now shrunken to 15 million ha (FAO 2007). Mangroves in India are distributed densely on the east coast and sparsely along the southwest coast. The identity of Indian mangroves is synonymous with the

Sundarbans mangroves distributed densely around 4921 km^2 (Sahana et al., 2015; Kathiresan 2018). A considerable density of mangroves is seen in Bhitarkanika Gahirmatha National Park, Odisha and Coringa Wildlife Sanctuary as well as Andhra Pradesh. However, they are all experiencing similar threats due to the developmental activities and growth of aquaculture farms.

The natural resources that have been destroyed need to be restored, and for that, a protection strategy has to be devised. A good conservation model needs a clear picture of what is left now with regard to its total extent and the details of diversity. Advent of satellite remote sensing and GIS tools can be used to study natural resources such as mangroves, coral reefs and sea grasses that are very widespread and difficult to learn and reach. Maps are widely used in oceanography and marine sciences for the representation of physical features as two-dimensional imageries. Assessment of biodiversity, mapping of features and retrieving information became more precise and effortless after the implementation of the latest tools using satellite remote sensing technology. The applications of remote sensing and mapping in marine biodiversity-related studies have significantly advanced in recent centuries (Rehman et al., 2021; Geller et al. 2017). Many of the coastal resources are not well studied because of their wider geographical coverage and inaccessibility (Giri et al. 2007). This limitation could be overcome by using the advents in satellite remote sensing and geographical information system (GIS) techniques for mapping and analysing coastal resources. An appropriate methodology is the need of the hour for environmental scientists at the regional level to contribute to the national archive of mangrove maps. The prime objective of this article is to provide a comprehensive overview and sound summary of spatial distribution of mangroves throughout the coastal region of Kerala using various GIS tools and techniques. Though they are distributed sparsely on the Kerala coast, when compared with the other states, mangroves of Kerala are known for their species diversity, and they need to be protected.

Several attempts were made for mapping mangroves across the globe using sentinel satellite data since the launch of Sentinel-2A in 2015 June and Sentinel-2B in March 2017. Irma Akhrianti (2019) conducted spatial distribution mapping of mangroves with Sentinel-2A imagery and GIS using maximum likelihood classification for mangrove in Kelapan Island, South Bangka Regency, Indonesia. Navarro et al. (2019) have integrated unmanned aerial vehicles (UAV) and Sentinel-1 and Sentinel-2 data for monitoring mangrove plantations above ground biomass in Senegal. Tieng et al. (2019) have used the combination of multiple satellite information such as Landsat-8 imagery, Sentinel-2 very-high-resolution images and Google Earth Engine algorithm for mapping the mangrove patches of Cambodia. Pham et al. (2019) conducted mangrove species mapping using Sentinel-1 and Sentinel-2 data in North Vietnam. Perea-Ardila et al. (2019) have mapped mangroves in the municipality of Buenaventura, Colombia, using Sentinel-2 image and high-resolution Orto-photomosaic of the municipality. Hu et al. (2020) carried out a case study in China on mapping of mangrove forests at national scale using Sentinel-1 and Sentinel-2 time-series data with Google Earth Engine. Nguyen et al. (2020) employed a combined use of Landsat 5/8, Sentinel-2A and Planet Scope for mapping mangrove extents and drivers of change in Thanh Hoa Province, Vietnam. Xue Liu et al. (2021) conducted large-scale high-resolution coastal mangrove forests mapping across West Africa with machine learning ensemble and satellite big data. In India, the study of mangroves using Sentinel satellite data is gaining popularity recently. Sudip Manna and Raychaudhuri (2019, 2020) conducted a mapping distribution of Sundarbans mangroves using Sentinel-2 data and coined a new spectral metric for detecting their health condition (Sahana et al., 2016; Sahana and Sajjad 2019). They have also conducted stress mapping of Sundarbans mangroves with Sentinel-2 images using Discriminant Normalised Vegetation Index (DNVI) and Fuzzy classification technique (2019).

This study is an attempt to identify and standardize the methodologies employed in mapping mangroves utilizing different satellite images and GIS-based software for mangroves distributed in Kerala, a southern state in India.

4.1.2 Mangroves in Kerala

Kerala, the southernmost state of India, lies between the latitudes 8°.17′.30″N and 12°.47′.40″N and longitudes 74°.27′.47″E and 77°37′.12″E. With nine coastal districts and five non-coastal districts, Kerala has a coastline of around 590 km which forms around 10% of the Indian coastline. Kerala is bestowed with the presence of 44 rivers, of which 41 fall into the Arabian Sea and the remaining 3 flow eastwards to the neighbouring states of Tamil Nadu and Karnataka. The coastline of Kerala is densely populated, and the livelihood of the majority of population depends on the income generated from the resources obtained from the natural habitats such as rivers, estuaries and wetlands. Mangroves in Kerala are distributed in the nine coastal districts and another one along the banks of Vembanad Lake (Estuarine district). Mangroves in Kerala are distributed densely in the Kannur and Kasaragod districts of Northern Kerala and Ernakulam district in the south. A comprehensive study of structural complexities and regeneration status of Kerala mangroves was carried out by George et al. (2019), reporting 16 mangrove species in Kerala (Fig. 4.1).

Fifteen species of mangroves were recorded by Vidyasagaran and Madhusoodanan (2014). Even though there are copious region-specific studies on the distribution and diversity of mangroves in Kerala, the delineation of entire patches of mangroves is still not carried out. In recent years, Kerala coast has been battered by natural catastrophes in the form of the 2004 *Tsunami*, *Ockhi* cyclone (2017), the century's largest deluge in 2018, followed by similar but less intensive flood in 2019. During these events, it was the mangroves that protected the coastal zones and the lives of the people. Historical studies on the extent of Kerala mangroves help determine the change in mangrove distribution and cover over a period of time. Ramachandran et al. (1985) have indicated that there were mangroves in Kerala distributed around 700 km^2. Connecting with the subsequent studies, this could be a slight over-estimation (Babbar et al., 2021). As per the

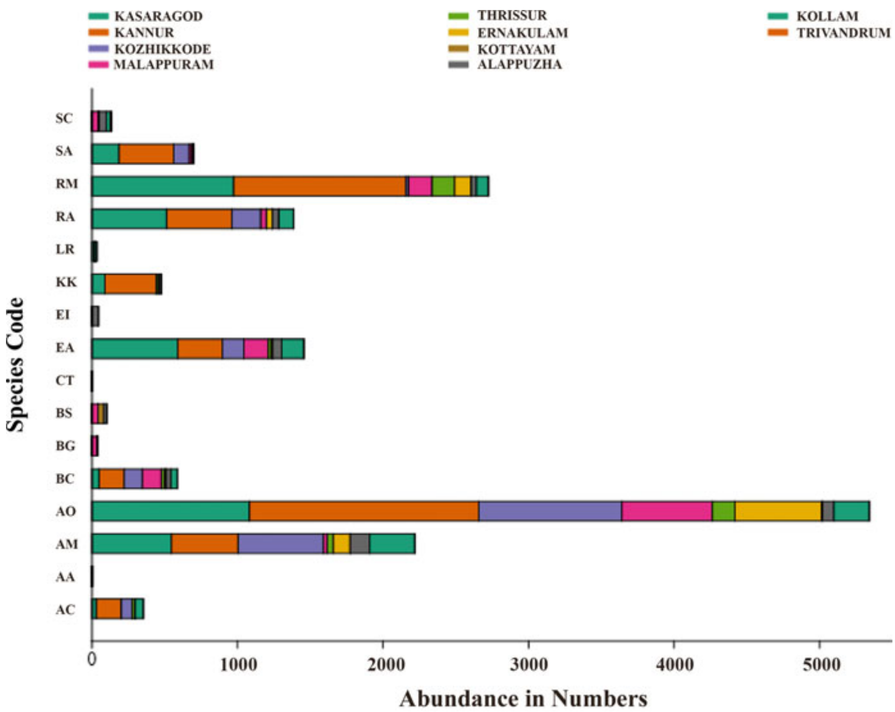

Fig. 4.1 Abundance of mangrove species in Kerala based on transect study. AC *Aegiceras corniculatum*, AA *Avicennia alba*, AM *Avicennia marina*, AO *Avicennia officinalis*, BC *Bruguiera cylindrica*, BG *Bruguiera gymnorhiza*, BS *Bruguiera sexangula*, CT *Ceriops tagal*, EA *Excoecaria agallocha*, EI *Excoecaria indica*, KC *Kandelia candel*, LR *Lumnitzera racemosa*, RA *Rhizophora apiculata*, RM *Rhizophora mucronata*, SA *Sonneratia alba*, SC *Sonneratia caseolaris*

studies carried out for the entire state during 1990–2020, it was observed that the extent of mangroves is found in a range of 10–40 km^2 (Table 4.1). However, historical studies on the aerial coverage of mangroves in Kerala reveal the extent of shrinkage that mangroves of Kerala have undergone during the past decade. The recent floods and natural catastrophes point to the need for the conservation of mangroves in the state for the protection of the coast as well as the coastal community.

4.1.3 Mapping of Mangrove Patches in Kerala

Compared with other coastal states in India, Kerala mangroves contribute around 800 hectares which is about 0.17% of the national mangrove spread (FSI 2005). As observed in the earlier reports, Kerala mangroves were distributed in 700 km^2 (Ramachandran et al. 1985) which got reduced to 800 ha in recent years. Many

Table 4.1 Comprehensive account of Kerala mangroves in the recent past

Mangroves forest/ region	Total area in km^2	Species reported	References
Kerala	700		Ramachandran et al. (1985)
Kerala	17		Basha (1991)
Kerala	9		Kurian (1994)
Kerala	42		Mohanan (1997)
Kerala	17	*Rhizophora mucronata*, *Avicennia officinalis*, *Avicennia marina*, *Kandelia candel*, *Excoecaria agallocha*, *Aegiceras corniculatum*	Muraleedharan et al. (2009)
Kerala	25.02	*Rhizophora mucronata*, *Rhizophora apiculata*, *Avicennia officinalis*, *Avicennia marina*, *Bruguiera cylindrica*, *Bruguiera gymnorhiza*, *Kandelia candal*, *Bruguiera sexangula*, *Sonneratia alba*, *Sonneratia caseolaris*, *Excoecaria agallocha*, *Excoecaria indica*, *Aegiceras corniculatum*, *Lumnitzera racemose*, *Ceriops tagal*	Vidyasagaran and Madhusoodanan (2014)
Kerala	25.05	*Acanthus ilicifolius*, *Acanthus ebracteatus*, *Avicennia marina*, *Avicennia officinalis*, *Aegiceras corniculatum*, *Bruguiera cylindrica*, *Bruguiera gymnorhiza*, *Bruguiera parviflora*, *Bruguiera sexangula*, *Ceriops tagal*, *Kandelia candel*, *Rhizophora apiculata*, *Rhizophora mucronata, Shirakiopsis indica*, *Excoecaria agallocha*, *Heritiera littoralis*, *Lumnitzera racemosa*, *Sonneratia alba*, *Sonneratia apetala*, *Sonneratia caseolaris*, *Nypa fruticans*, *Phoenix sylvestris*, *Phoenix humilis*, *Acrostichum aureum*	Mohandas et al. (2014)
Kerala	9		FSI (2015)
Kerala	16	*Avicennia officinalis*, *Avicennia marina*, *Rhizophora apiculata*, *Rhizophora mucronata*, *Bruguiera cylindrica*, *Bruguiera gymnorhiza*, *Bruguiera sexangular*, *Excoecaria agallocha*, *Aegiceras corniculatum*, *Ceriops tagal*, *Kandelia candel*, *Sonneratia caseolaris*, *Sonneratia alba*	George et al. (2019)
Kerala	9		FSI (2019)

government organizations and NGOs strive to conserve the mangroves in Kerala, but accurate information on individual patches of mangroves is very limited. This is one major lacuna in framing a conservation plan for the mangroves in Kerala. The attempts to map by visiting individual mangrove patches are time-consuming and expensive. The proper delineation with the help of remote sensing satellite data would help improve the understanding of the current status and long-term monitoring of mangroves.

4.2 Spatial Distribution of Mangrove Patches in Kerala

The study area is between 12.62°N, 74.92°E and 08.51°N, 76.89°E (Fig. 4.2). GPS points for each location and the extent of mangrove patches identified were marked and documented.

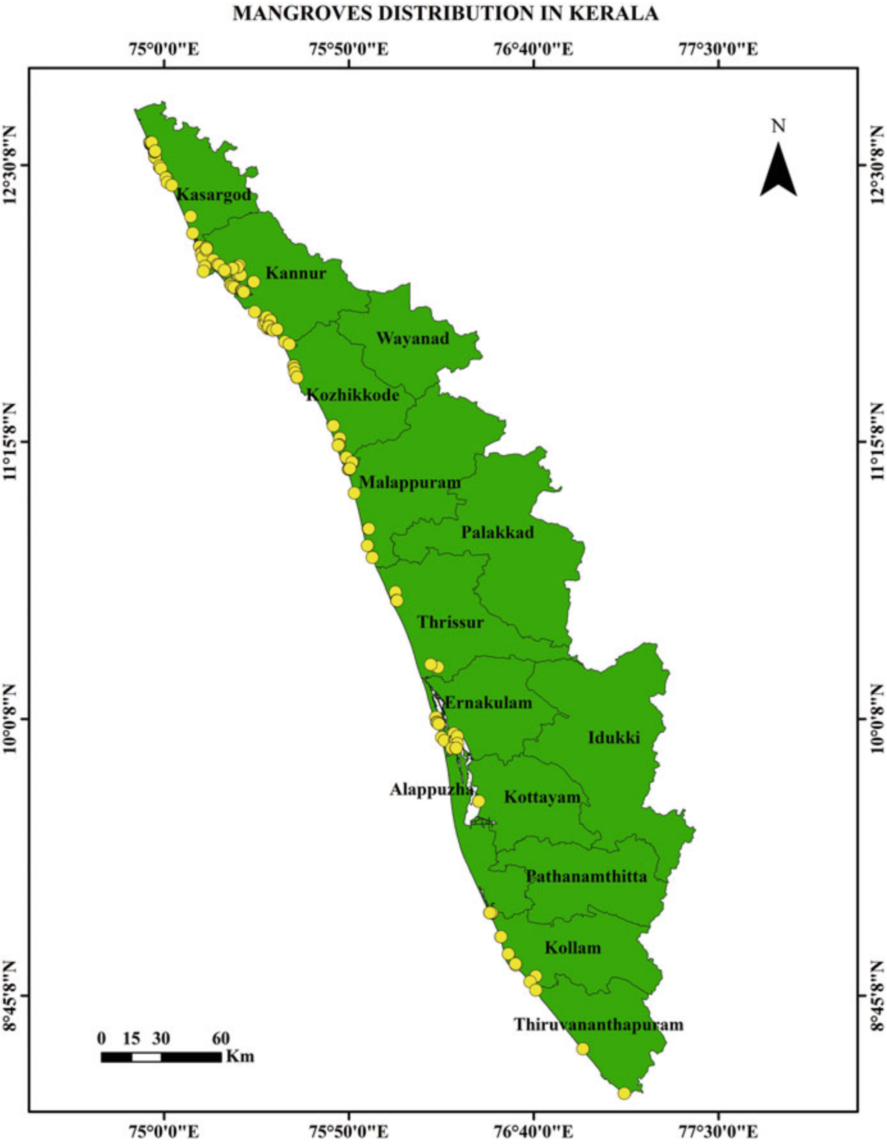

Fig. 4.2 Mangrove patches (Yellow dots) in Kerala indicated as ground control points (GCPs)

4.3 Gathering Information on the Mangrove Patches Through Field Surveys

Extensive field surveys were conducted throughout the 65 mangrove patches identified in ten districts of Kerala (Fig. 4.2). Diversity assessment of each patch was carried out (Fig. 4.3) by the following Line Intercept Transect (LIT)/Transect line plot (Loya 1978; Marsh et al. 1984). In each site, three transects each of 100 × 100 m area and three quadrats 10 × 10 m were laid randomly within the mangrove forest area. Seedlings, saplings and trees in each quadrat within the transect belt were categorized according to the height measurements. The girth of the tree or sapling was measured at breast height. Circumference (in cm) and height (in m) were measured using a flexible measuring tape. Photographs were taken using NIKON DSLR D90 camera. GPS coordinates of each patch were recorded using Garmin GPS (Model etrex10).

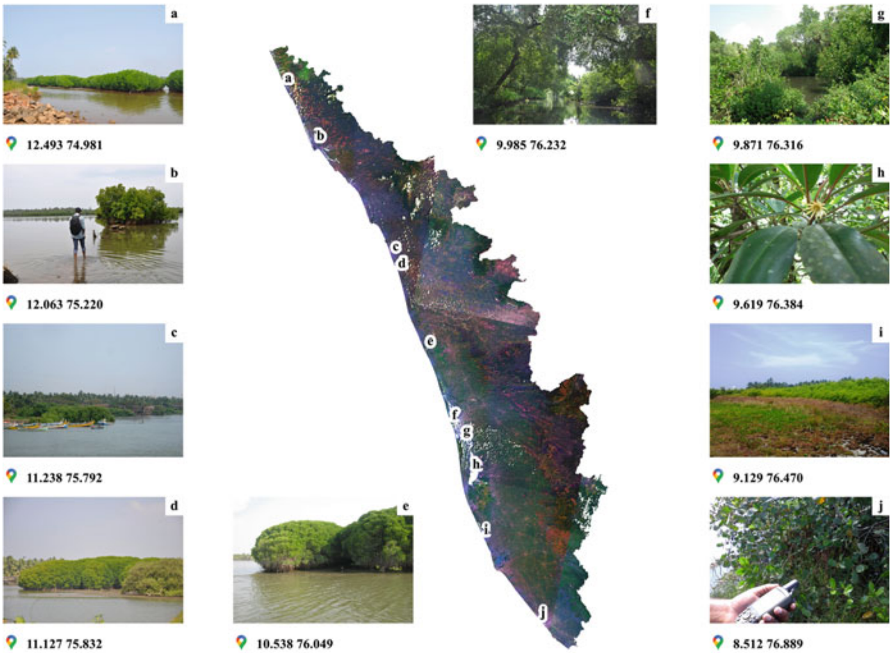

Fig. 4.3 Glimpses of field visits throughout the ten coastal districts of Kerala

4.4 How to Map Mangrove Patches: Methods and Data Sets

Mapping of mangroves using satellite remote sensing and GIS techniques got popularized among the scientific community in the recent two decades (George 2014). Many satellites such as IKONOS and QuickBird provide super spectral and PAN images even at a resolution of 0.5 m, but these data are not available free of cost. The European satellite Sentinel-2 multispectral images (MSI) with a resolution of 10 m and Synthetic Aperture Radar (SAR) images from the Sentinel-1 satellite provide free data for research purposes that are now being widely used for identifying mangrove patches worldwide (Guo et al. 2019). The data are freely available on the USGS website and Copernicus data hub, and these products can be downloaded free of cost. The multispectral images of Sentinel-2 contain 13 (443–2190 nm) bands with different spatial resolution from 10 m (four visible and near-infrared bands) to 60 m with a swath width of 290 km (six red edge and shortwave infrared bands) and 60 m (three atmospheric correction bands). The free and open-source software by the European space agency (ESA) SNAP and Acolite by Royal Belgian Institute of Natural Sciences can be used for processing the Sentinel data. Quantum GIS is the best recommended open-source software for constructing maps. Validation of the satellite-derived outputs can be done using the ground control points collected during manual field surveys. In this study, we attempted to map mangrove patches in Kerala by employing different methodologies. The best methodology for mapping mangrove patches was ranked as an output of this study by comparing the accuracy and precision among these different methods.

Three methods were used in this study such as mapping of mangroves using Google Earth Pro KML polygons, application of various supervised classification algorithms using Sentinel-2 images in SNAP and maximum likelihood classification in QGIS using the same Sentinel-2 satellite data. These three models were performed, and the best two among these three methods were used for the delineation of the entire mangrove patches in Kerala.

In the present study, the identification and distribution of mangroves in Kerala was carried out using European space agency (ESA) satellite series Sentinel-2A and 2B satellite data. The advantage of using Sentinel satellite data is that the satellite revisits the same location and the number of acquisitions in a shorter duration.

4.5 Various Methods Employed for Mapping Mangroves

4.5.1 Google Earth Images (Google Earth Pro: Version 7.3.3.7786)

The Google Earth images are combined imageries of various satellite programmes such as Landsat, Copernicus, WorldView and QuickBird by Digital globe technologies under Maxar Technologies. These images are updated periodically, easily accessible and freely available in the Google Earth Pro software. This is one of the

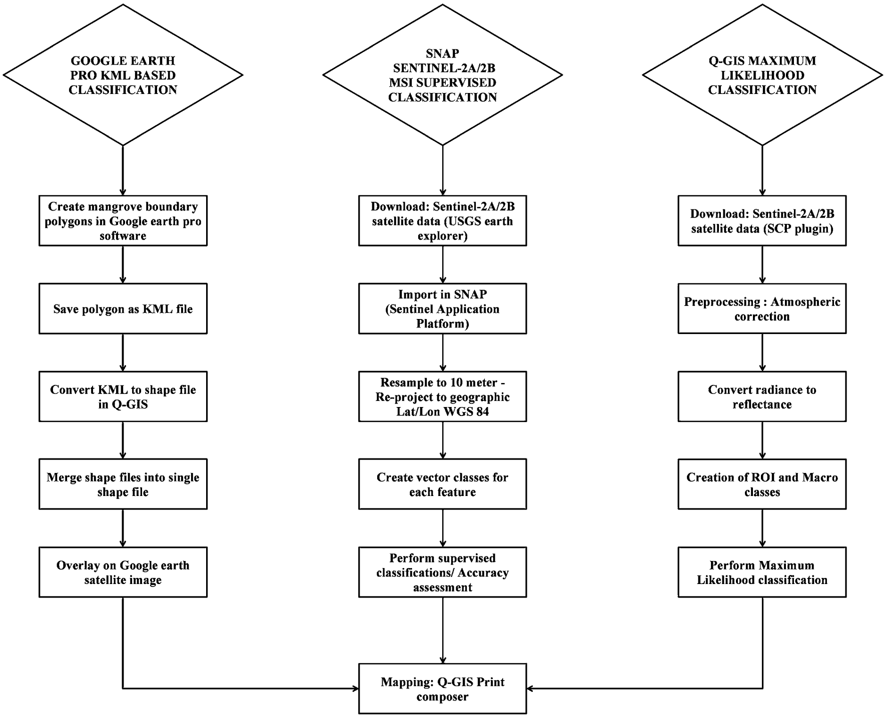

Fig. 4.4 Schematic diagram displaying different methodologies employed in this study

basic tools used for mapping mangroves. Google Earth Pro (**Version 7.3.3.7786**) software was used for this study. Geo-referenced polygons were generated over mangrove patch boundaries (Fig. 4.4) in all the 59 mangrove patches recognized in the state through the field survey. The major advantage of this software is the availability of time series maps from 1985 onwards. The comparison of mangroves over years can be done using Google Earth images. The KML (Keyhole Markup Language) files generated in the Google Earth Pro software were imported into QGIS software and then converted as shapefiles. Multiple shapefiles were merged using a vector combiner and later mapped with a print composer in QGIS. Area of the individual mangrove patch was also documented.

4.5.2 Sentinel-2 MSI (Multi-spectral Images) (Sentinel Application Platform Version 8.0)

Sentinel-2 data is downloaded from both Copernicus data hub (Copernicus Open Access Hub) and USGS Earth Explorer (Earth explorer USGS) websites. The Level-1C (L1C) product of the Sentinel-2 satellite was (Table 4.2) used in this study. Further processing of satellite data was carried out in SNAP. Sentinel-2 L1C images

Table 4.2 List of Sentinel imagery (scenes) used for the study

Mission	Product code	Observation date	Tile	Cell size (m)	Swath width (km)
Sentinel-2A	MSIL1C	20200411T051651	PDQ	10	290
Sentinel-2A	MSIL1C	20200411T051651	PDP	10	290
Sentinel-2A	MSIL1C	20200112T052201	PEP	10	290
Sentinel-2A	MSIL1C	20200122T052111	PEP	10	290
Sentinel-2A	MSIL1C	20200122T052111	PEN	10	290
Sentinel-2A	MSIL1C	20200211T051941	PFM	10	290
Sentinel-2A	MSIL1C	20200218T050851	PFM	10	290
Sentinel-2A	MSIL1C	20200124T051109	PFL	10	290
Sentinel-2A	MSIL1C	20200228T050741	PFK	10	290
Sentinel-2A	MSIL1C	20200707T050701	PGK	10	290

were atmospherically corrected, resampled to 10 meters and re-projected into the WGS-1984 coordinate referencing system (CRS). There are different methods for classifying mangroves in SNAP such as the random forest method, maximum likelihood classification and K-nearest neighbour classification (Fig. 4.4). Among these classification methods, the best performed method was used for further image classifications. This image classification was done based on the trained vectors created over the known features identified during the field survey. Vector classes for mangroves, waterbody, dense vegetation, bare land and buildings were identified from the field surveys and high-quality Google Earth images. Features with similar pixel values were classified and mapped. QGIS software was used for further analysis and processing. The maps were created by the QGIS map composer.

4.5.3 Semi-automatic Classification Plugin (SCP) in QGIS (Version QGIS 3.10)

Semi-automatic Classification Plugin (SCP) is the recent plugin addition in QGIS. This feature enables to download the various satellite images effortlessly. The semi-automated classification plugin features automatic atmospheric correction tools. Here, in this study, the same Sentinel-2A MSI used for classification using SNAP were used for SCP. The images were layer stacked (green, red and near-infrared bands) to make virtual band sets. Macro classes were prepared in the stalked images (Training areas) on the known features that were collected during field surveys, and a maximum likelihood classification was done (Fig. 4.4). The areas were marked as five different classes such as mangroves, dense vegetation, buildings, water body and bare land. Based on the pixel value difference of each feature, the area was classified into different classes.

A dense mangrove patch in the Ernakulam district of Kerala was taken as a sample classification site, and all the three classification methods were tested.

4.6 Accuracy Assessment of Image Classifications

The classification accuracy of classified images was carried out with the help of ground control points (GCPs) collected through the extensive field surveys in all the 59 mangrove patches distributed throughout the state and also from the high-resolution Google Earth image software. Approximately one-third of the reference data (a total of 250 GCPs), homogeneously distributed, were utilized to assess the accuracy. The accuracy of all the three classification schemas used in the study was subjected to an accuracy assessment by measuring the Cohen's kappa coefficient formula:

$$K = \frac{P_o - P_e}{1 - P_e}$$

where K = Kappa coefficient.

4.7 Results and Discussion

In the present study, among the three different methods employed (Fig. 4.5) for mapping mangroves, the two best methods with relatively higher accuracy were used for mapping and delineating the entire mangrove patches in Kerala. Here, the conventional mapping technique using KML files in Google Earth and Sentinel-2A satellite data-based RF classification with overall classification accuracy 84% in SNAP were identified as the two best methods based on the field validation.

Fig. 4.5 Outputs of various methodologies and techniques employed for mapping mangroves of Kerala

4.7.1 Delineation of Mangrove Patches Using Google Earth Images

The presence of mangroves was observed in nine coastal districts and one estuarine district in Kerala (Table 4.3). About 65 mangrove patches were marked in Google Earth Pro images from the preliminary visual assessment, and all the mangrove patches were field verified with the ground control points, and coordinates for all patches (Fig. 4.7a) were collected for the verification and mapping. After field surveys, it was confirmed that there are about 59 mangrove patches distributed all along the ten districts of Kerala, and the remaining six were identified as non-mangroves.

Kannur district in Northern Kerala had the maximum dense mangrove patches—around 20 mangrove patches were observed and delineated. The number of mangrove patches was relatively less in the southern districts of Kerala in comparison with the northern belts (Figs. 4.6 and 4.7).

4.7.2 Delineation of Mangrove Patches Using SENTINEL-2A/B Using SNAP

Three different classification algorithms were performed for selecting the best suitable algorithm for mapping the contiguous mangrove patches in Kerala. Maximum likelihood classifications (MLC), K-nearest neighbour classification (KNN) and random forest classification (RF) are the three different algorithms employed for Sentinel-2 satellite data in SNAP (Fig. 4.8). From these three different classifications, random forest classification gave the best classification accuracy compared to the other two classification methods. The accuracy of the classification performance was validated using the ground control points selected from individual mangrove patches along the coastal regions in Kerala. Based on the results of the RF classification, 59 patches of mangroves in Kerala from the Kasaragod district situated in the northern tip of Kerala to Trivandrum in the southern tip of Kerala state were classified, marked and delineated, and mapped using QGIS (Figs. 4.9, 4.10, 4.11, 4.12, 4.13, 4.14, and 4.15).

4.7.3 Accuracy Assessment

The accuracy assessments for mangrove classification were carried out for the dense mangroves in the Ernakulam district of Kerala, the second-largest mangroves in Kerala in terms of spatial coverage (Table 4.4a, b and c). The producer's accuracy and users' accuracy were used to understand the overall accuracy of the classification. It is evident from the analysis that the RF classification method gave a higher accuracy for the mangrove classification ($K = 0.80$) compared to KNN ($K = 0.61$) and MLC ($K = 0.685$).

Table 4.3 Details of mangrove patches identified in various districts of Kerala

District	Sl. no	Patch no	Latitude	Longitude	Area (m^2)	District	Sl. no	Patch no	Latitude	Longitude	Area (m^2)	District	Sl. no	Patch no	Latitude	Longitude	Area (m^2)
Kasaragod	1	1	12°35.754	074°56.374	96158.38		21	23	11°50.369	075°24.551	91605.54		41	44	10°43.819	75°56.389	16593.37
	2	2	12°35.856	074°56.525	268199.7		22	24	11°47.957	075°27.136	78077.58	Thrissur	42	45	10°34.380	76°02.609	26188.16
	3	3	12°32.170	074°57.648	73959.37		23	25	11°48.884	075°27.841	123367.3		43	46	10°32.303	76°02.968	57567.96
	4	4	12°33.658	074°57.438	23341.09		24	26	11°47.951	075°28.730	64653.31		44	47	10°14.381	76°13.303	852596.3
	5	5	12°29.617	074°58.786	278240.5		25	27	11°45.861	075°28.089	61621.01	Ernakulam	45	48	10°00.424	76°13.701	44378.25
	6	6	12°26.744	075°00.648	3016.115		26	28	11°47.403	075°28.750	109667.2		46	49	9°59.250	76°13.857	1,248,739
	7	8	12°24.644	075°02.170	23.3532		27	29	11°45.384	075°29.447	99452.34		47	50	9°58.536	76°15.920	14,503
	8	10	12°11.705	075°07.817	886.704		28	30	11°42.181	075°32.773	29125.58		48	51	9°55.852	76°18.551	269,675
	9	11	12°08.104	075°09.659	28335.19		29	31	11°41.550	075°33.909	46192.87		49	52	9°55.161	76°15.149	395154.5
Kannur	10	12	12°07.111	075°11.511	16467.14	Kozhikkode	30	32	11°35.731	075°35.130	38473.88		50	53	9°54.397	76°18.692	576190.4
	11	13	12°07.841	075°11.532	157200.9		31	33	11°33.756	75°35.521	16653.79		51	54	9°53.489	76°19.347	10,546
	12	14	12°03.478	075°13.301	619647.3		32	34	11°32.597	75°35.999	22728.56	Alappuzha	52	55	9°52.131	76°17.913	417631.1
	13	15	12°02.641	075°11.155	5636.23		33	35	11°19.524	75°45.857	2089.3	Kottayam	53	56	9°37.869	76°25.138	54589.0
	14	16	12°03.089	075°14.494	160,713		34	36	11°16.029	75°47.587	233400.7	Kollam	54	57	9°07.494	76°28.703	174951.4
	15	17	12°01.320	075°10.681	1,290,992		35	37	11°14.285	75°47.461	75977.11		55	58	9°01.099	76°31.167	9794.58
	16	18	12°02.926	075°20.362	415415.1		36	38	11°10.919	75°49.285	122418.9		56	59	8°56.450	76°33.239	274855.3
	17	19	12°01.566	075°16.507	312580.5		37	39	11°09.415	75°50.982	10282.99		57	60	8°53.501	76°35.138	9289.01
	18	20	11°57.776	075°18.077	697,779	Malappuram	38	40	11°07.709	075°49.944	140,801		58	61	8°50.360	76°40.528	7457.93
	19	21	11°56.052	075°20.977	299271.4		39	42	10°51.582	75°55.265	150500.1	Trivandrum	59	64	8°30.741	76°53.377	14388.83
	20	22	11°58.433	075°24.181	18290.98		40	43	10°46.972	75°55.130	16308.92	**Total**	**59**	**59**			**10,760138**

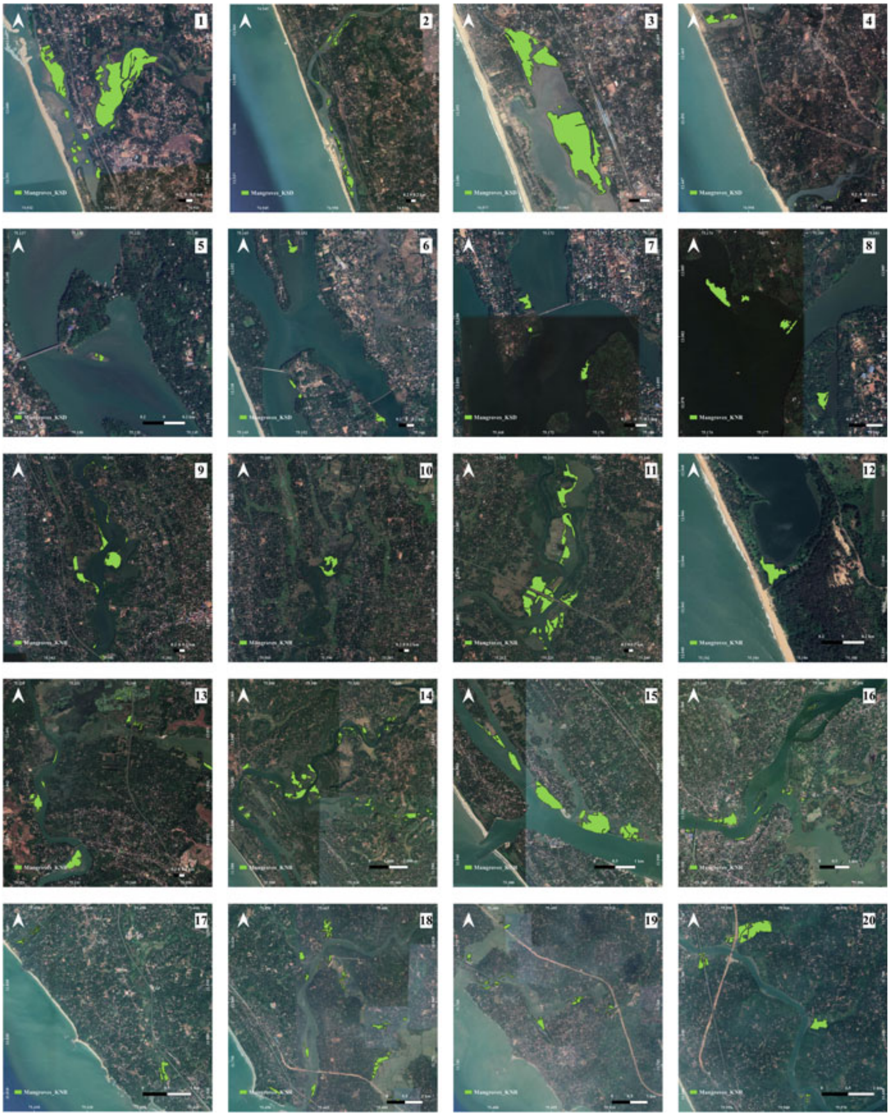

Fig. 4.6 (**a**) Kasaragod Mangroves (1–7), Kannur Mangrove patches (8–20). (**b**) Mangroves patches in Kozhikode (21–26), Malappuram (27–30), Thrissur (31–32), Ernakulam (33–35), Alappuzha (36–37), Kottayam (38), Kollam (39–42) and Trivandrum (44)

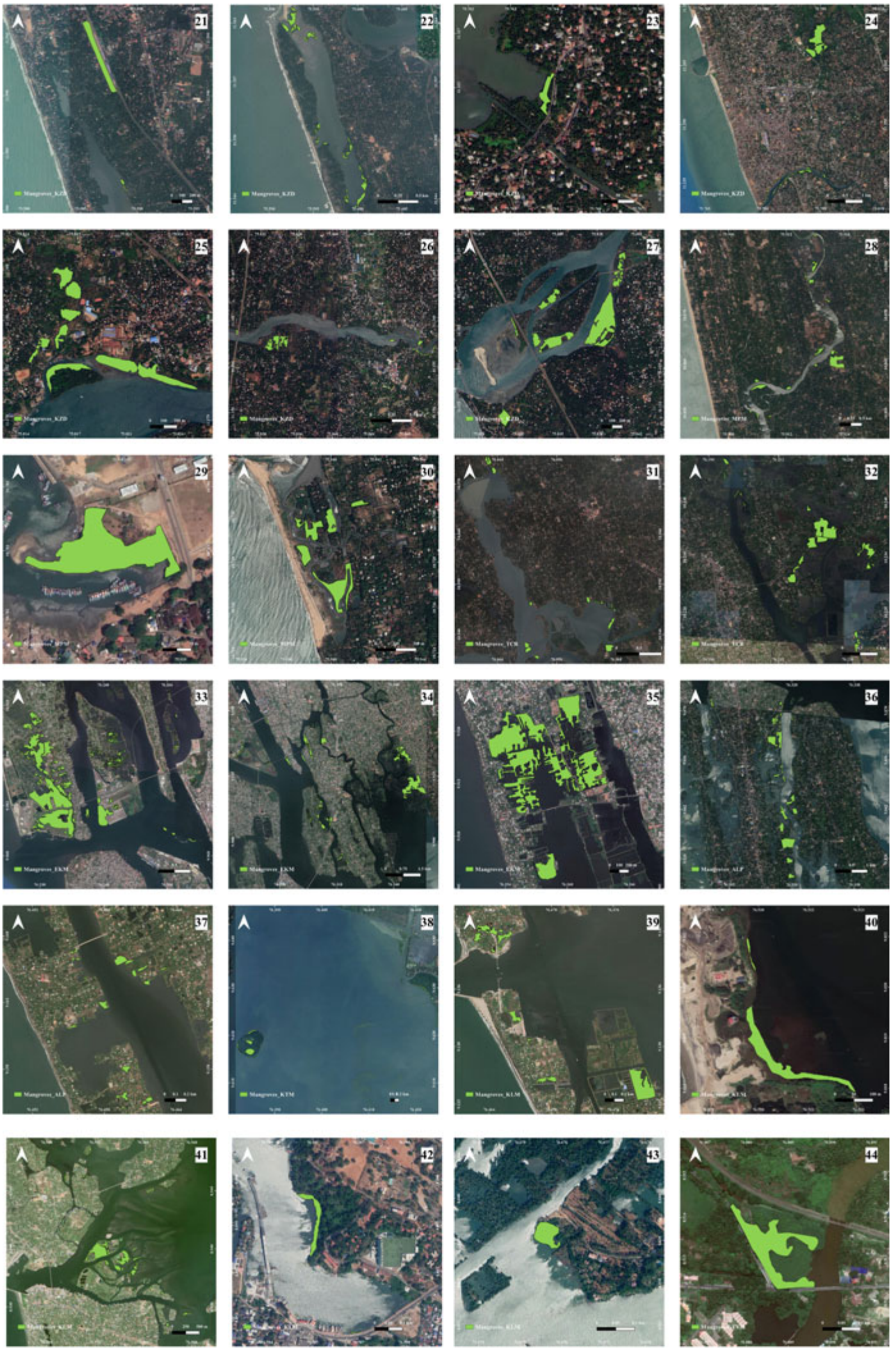

Fig. 4.6 (continued)

Fig. 4.7 Distribution and plant diversity of mangroves along Kerala coast

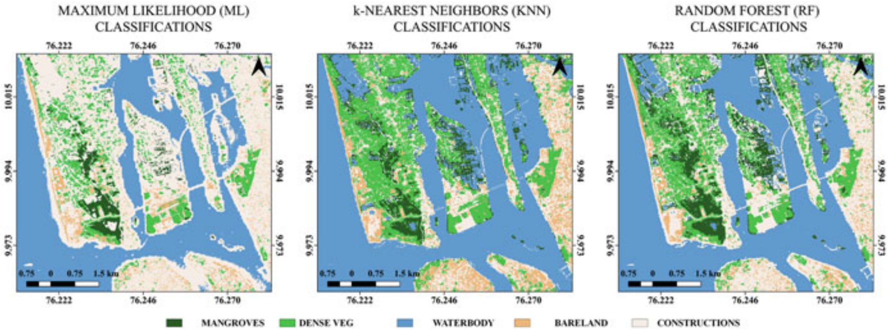

Fig. 4.8 Comparison of different algorithms tested for mapping mangroves in SNAP

4.8 Summary and Conclusion

Delineation of mangrove patches is essential as they are degrading to a larger extent over a short period. This could be due to the developmental activities and human perturbations in the coastal zone. The Indian government adheres to strict rules in the coastal zones by implementing the coastal regulation zone CRZ I Act, 2005. Also, the recently updated CRZ notification 2018 by MoEFCC (Ministry of Environment, Forest and Climate Change) points to the importance of Ecologically Sensitive Areas (ESA) and the protection and livelihood of people residing on the coast. Amid the strict laws, fast-paced deterioration of the coastal features was observed mainly due to the lack of awareness among people about their importance. A proper conservation strategy needs to be framed for making a better conservation plan. The Indian mangroves are not scientifically marked due to the vast area and lack of expertise and involvement of people in this area.

In this study, we delineated mangroves in Kerala using different methodologies. With this study, we were able to delineate mangrove patches in Kerala using two different methodologies. The Google Earth KML-based classification of mangroves is relatively easy and less expensive compared with other methods performed using satellite images. The KML files of mangroves can be created for various periods because the satellite images for the last two decades are available in Google Earth Pro software. From the studies, we observed that the major constraint of this method is the incidence of non-mangroves in these polygons that are mapped as mangroves as it is difficult to distinguish between non-mangroves and mangroves from mixed vegetation while creating polygons. The random forest classification was the best in classifying mangrove patches in Kerala. The major advantage of Sentinel-2 multispectral images is the higher temporal and spatial resolution, but the presence of clouds in the image was noticed as a major setback of Sentinel-2 satellites.

The present study was able to establish a standardized methodology for mangrove mapping in Kerala. This can be extended on a national scale to create a national mangrove library to understand and strengthen the conservational plan for the

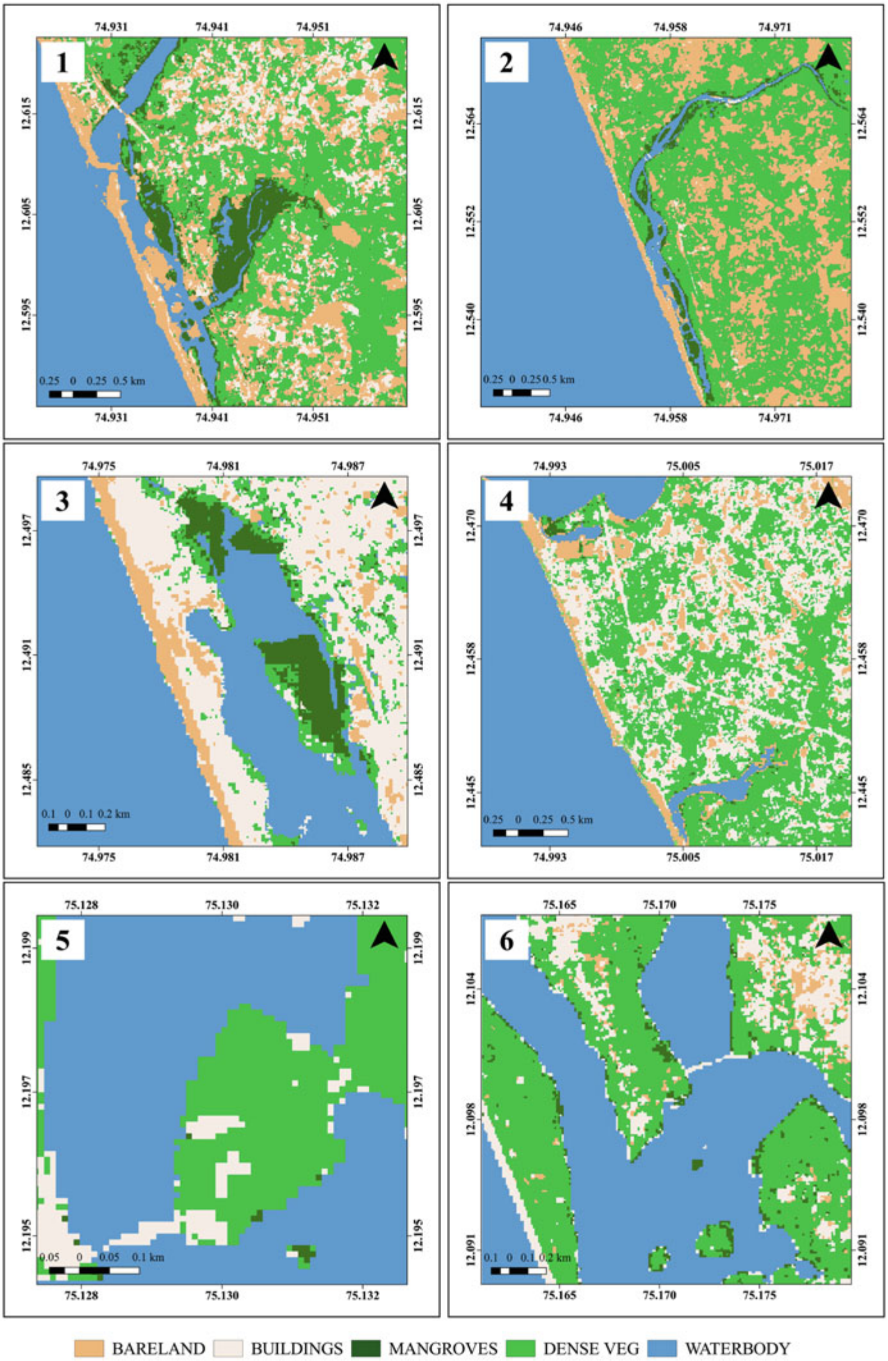

Fig. 4.9 Kasaragod mangrove patches (1–6)

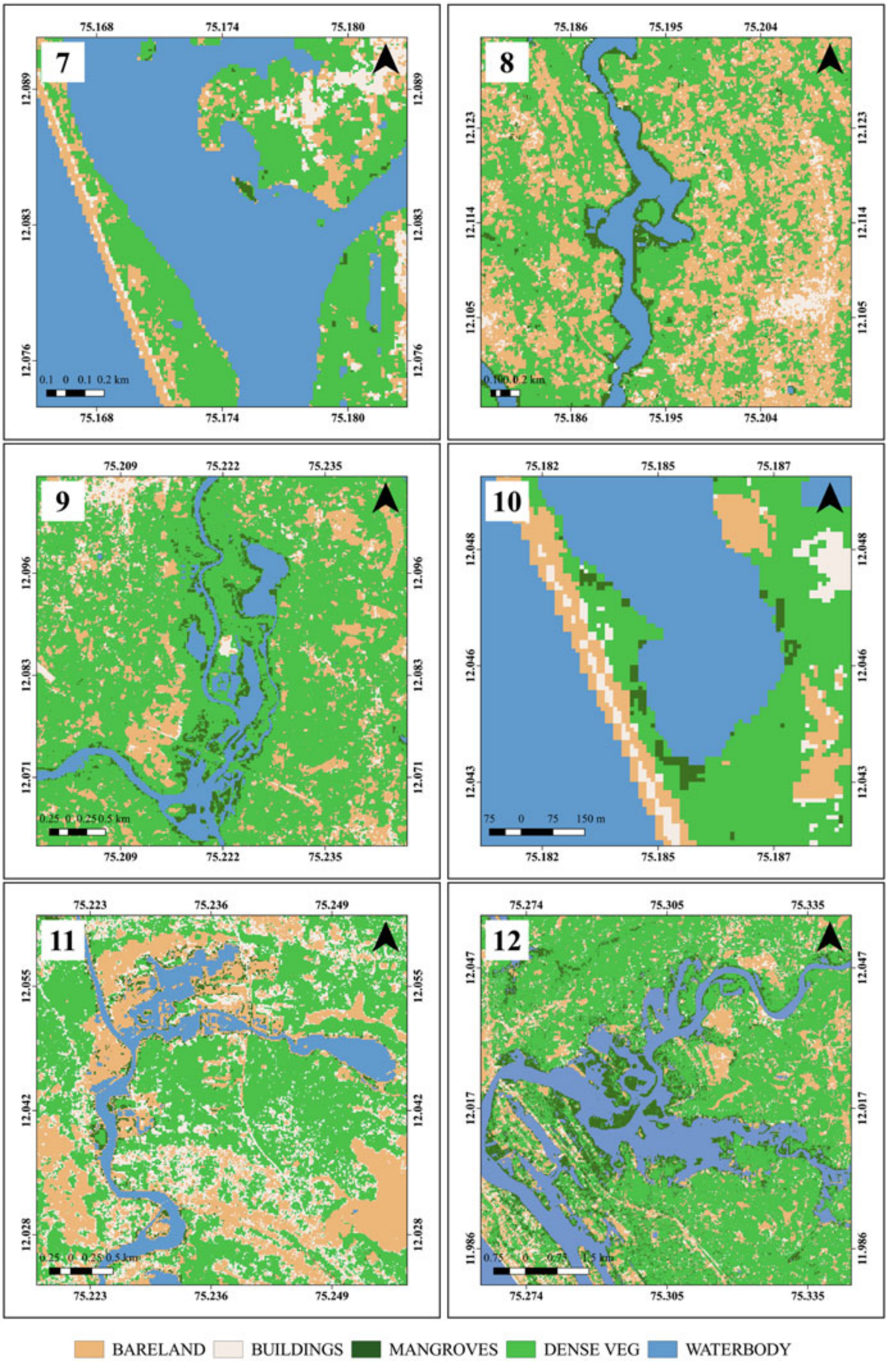

Fig. 4.10 Kannur Mangrove patches (7–12)

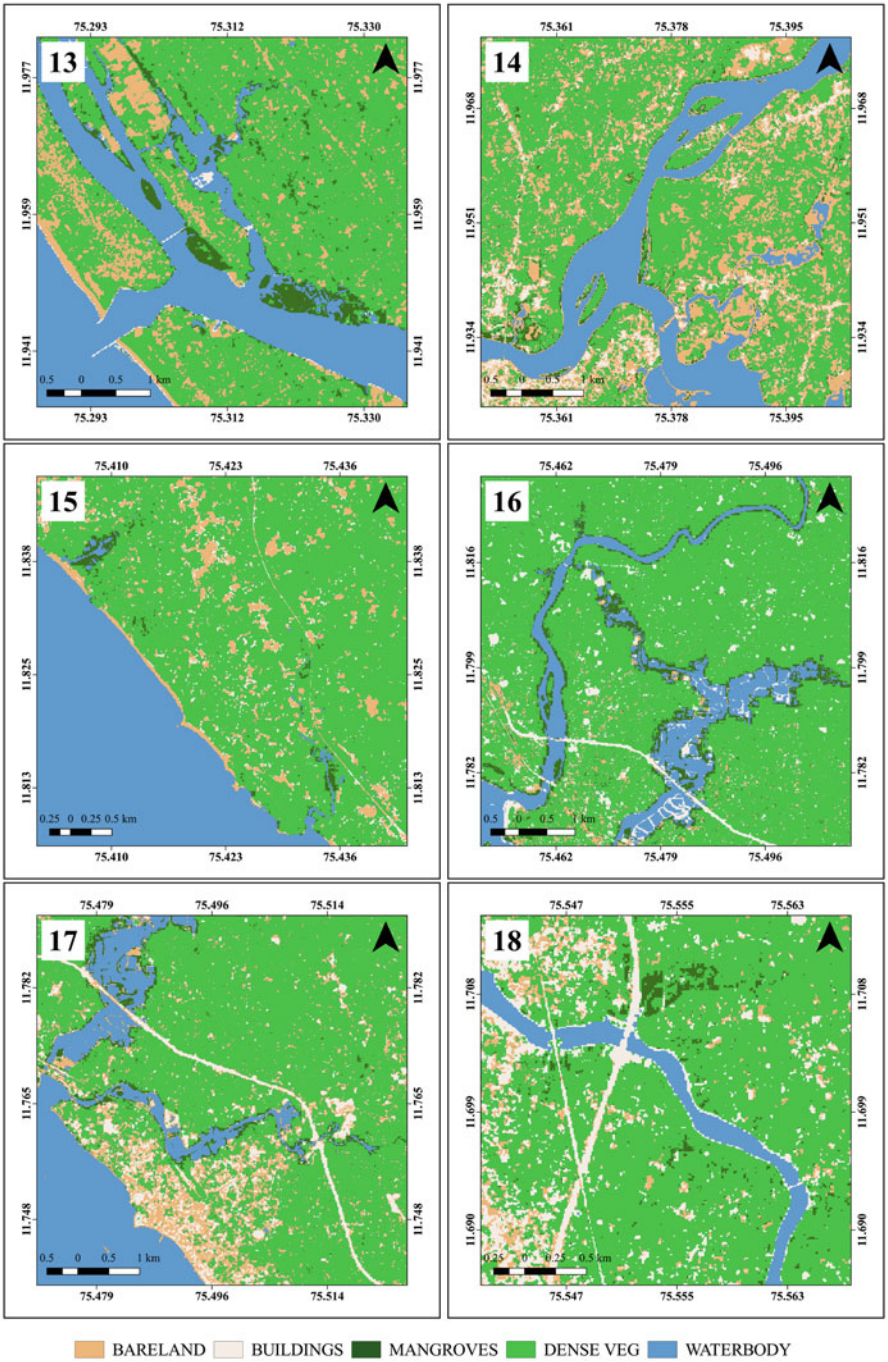

Fig. 4.11 Kannur Mangrove patches (13–18)

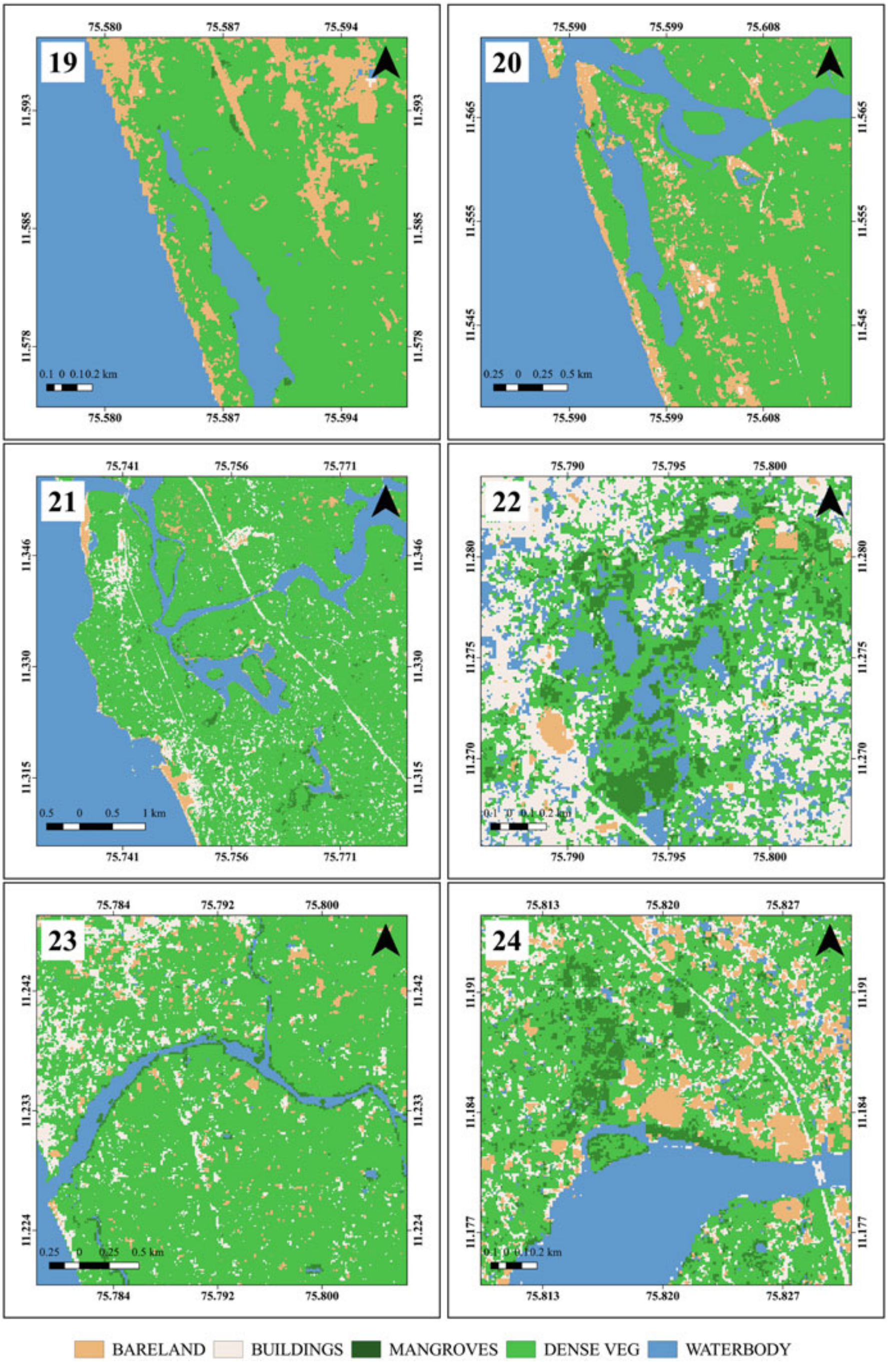

Fig. 4.12 Mangroves patches in Kozhikkde (19–24)

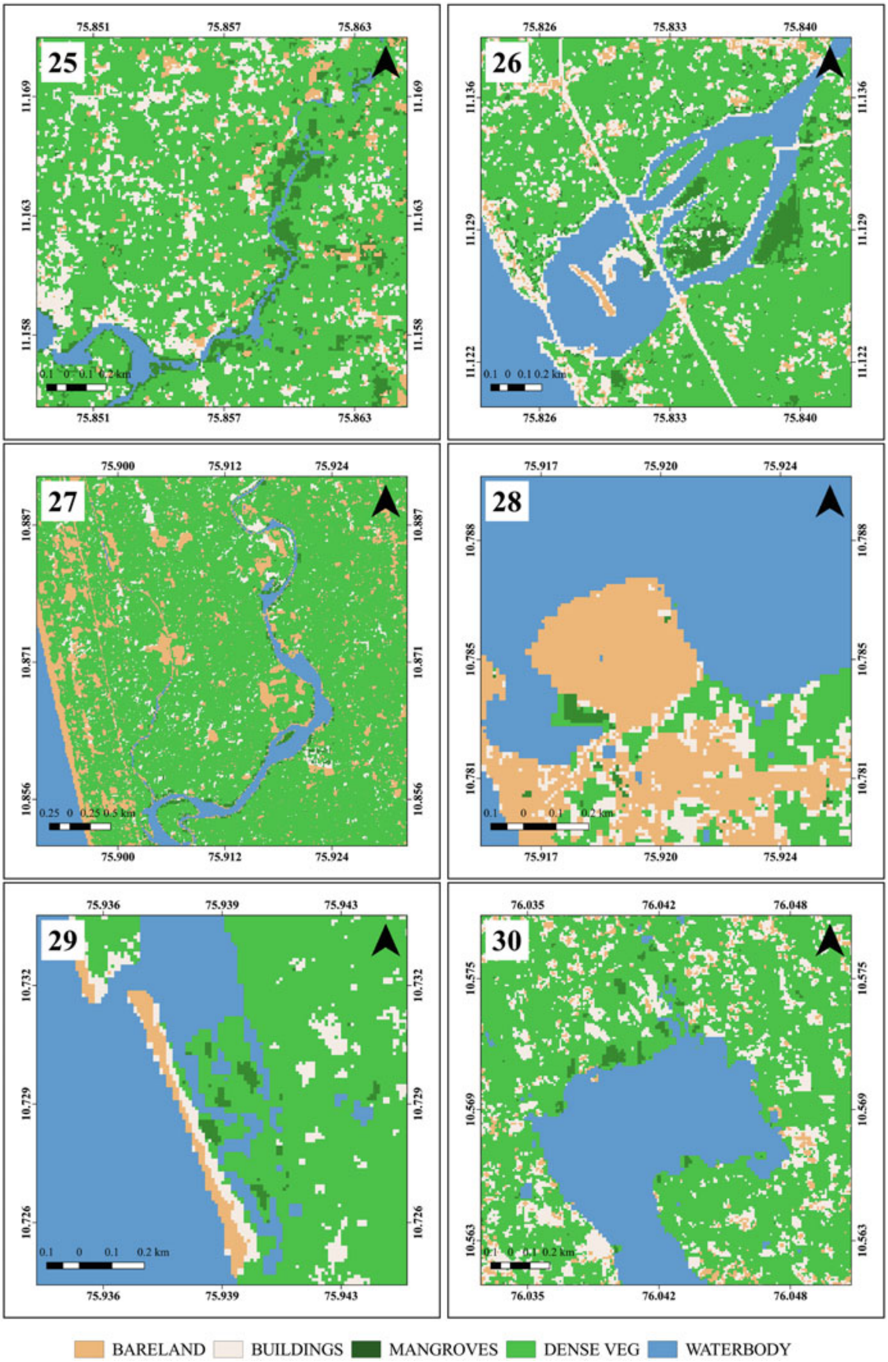

Fig. 4.13 Mangroves patches in Kozhikkde (25), Malappuram (26–29), Thrissur (30)

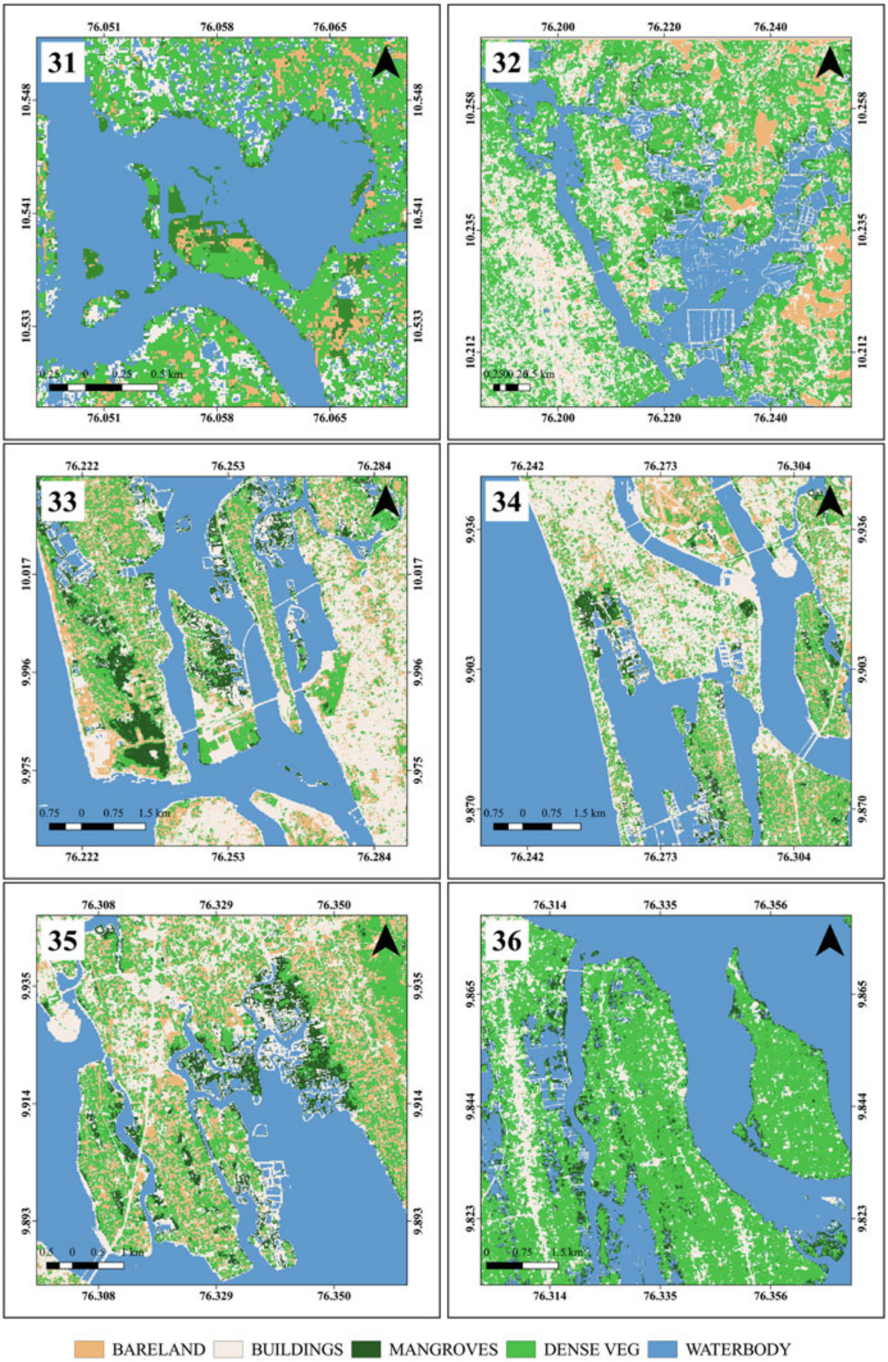

Fig. 4.14 Mangroves patches in Thrissur (31), Ernakulam (32–35), Alappuzha (36)

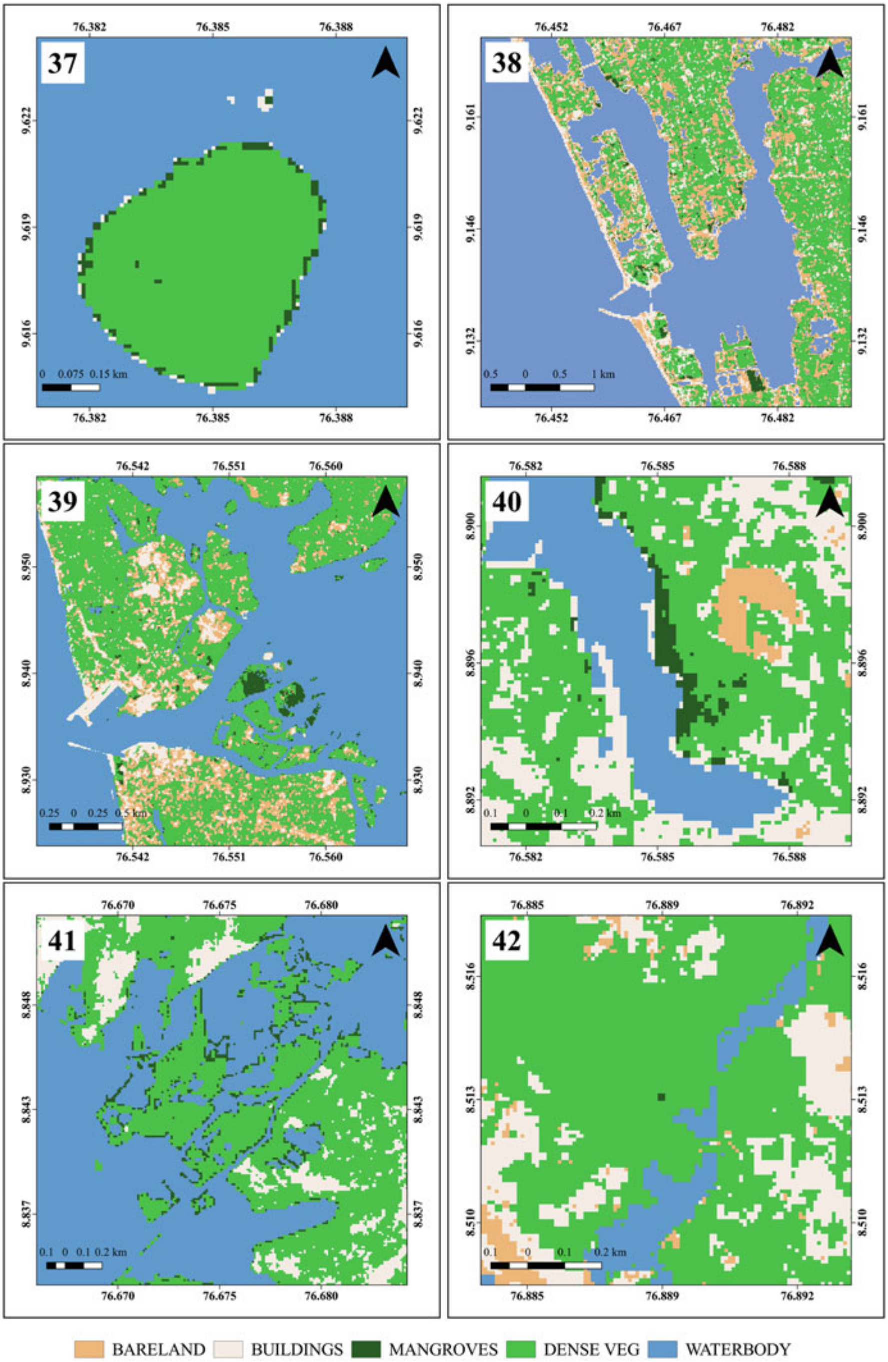

Fig. 4.15 Mangroves patches in Kottayam (37), Kollam (38–41) and Trivandrum (42)

Table 4.4 Accuracy of classifications: (a) RF, (b) MLC, (c) KNN and (d) MLC in QGIS

(a)

Classes	Water	Mangroves	Bareland	Dense veg	Buildings	Total	Commission error	User accuracy
Water	45	2	0	0	3	50	10%	90%
Mangroves	0	48	0	2	0	50	4%	96%
Bareland	0	1	43	3	3	50	14%	86%
Dense veg	0	2	0	46	2	50	8%	92%
Buildings	0	0	22	0	28	50	44%	56%
Total	45	53	65	51	36	250		
Omission error	0%	9.43%	33.85%	9.80%	22.22%			
Producers accuracy	100%	90.57%	66.15%	90.20%	77.78%			
Overall classification accuracy	84%							
Kappa coefficient	**0.8**							

(b)

Classes	Water	Mangroves	Bareland	Dense veg	Buildings	Total	Commission error	User accuracy
Water	27	1	0	0	22	50	46%	54%
Mangroves	0	42	0	3	5	50	16%	84%
Bareland	0	0	36	0	14	50	28%	72%
Dense veg	0	2	0	45	3	50	10%	90%
Buildings	0	0	13	0	37	50	26%	74%
Total	27	45	49	48	81	250		
Omission error	0%	6.67%	26.53%	6.25%	54.32%			
Producers Accuracy	100%	93.33%	73.47%	93.75%	45.68%			
Overall classification accuracy	74.80%							
Kappa coefficient	0.68							

(c)

Classes	Water	Mangroves	Bareland	Dense veg	Buildings	Total	Commission error	User accuracy
Water	46	1	0	0	3	50	8%	92%
Mangroves	0	43	0	7	0	50	14%	86%
Bareland	0	1	25	13	11	50	50%	50%
Dense veg	0	2	0	45	3	50	10%	90%
Buildings	4	0	33	0	13	50	74%	26%
Total	50	47	58	65	30	250	100%	
Omission error	8%	8.51%	56.90%	30.77%	53.33%			
Producers accuracy	92%	91.49%	43.10%	69.23%	43.33%			
Overall classification accuracy	68.80%							
Kappa coefficient	0.61							

(d)

Classes	Water	Buildings	Dense veg	Bareland	Mangroves
Water	0.45	0	0	0	0

(continued)

Table 4.4 (continued)

(d)					
Classes	Water	Buildings	Dense veg	Bareland	Mangroves
Buildings	0	0.09	0	0.01	0
Dense veg	0	0.003	0.18	0.003	0
Bareland	0	0.10	0.00	0.08	0
Mangroves	0	0	0.00	0	0.04
Total	0.45	0.20	0.19	0.09	0.04
PA[%]	100	45.92	94.31	83.43	99.98
UA [%]	99.99	88	96.8	40.96	91.29
Kappa hat	0.99	0.84	0.96	0.34	0.90
Overall accuracy [%]	86.01				
Kappa hat classification	0.8				

dwindling mangrove flora of India. Also, the Swaminathan committee's recommendations on Coastal Regulation Zone, 2001 for the protection of coastal zones by building a "BIOSHIELD" and mapping of mangroves in India also can be accomplished.

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Authors' Contribution Pranav P: Carried out field sampling and analysis, wrote the MS.

Nandini Menon N: editing, revision of the manuscript and technical support, coordination of this work among authors.

Shameem U: Mentoring the student, work conceptualization, supervision and editing.

Mini KG: coordination of the project, data management, project management, manuscript revision and coordination in the Institute.

Grinson George: project conceptualization, mentoring, fund management, project implementation, data management, manuscript revision and correspondence.

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Part II
Forest Conservation and Society

Chapter 5
Significance of Social Systems in Forest and Biodiversity Conservation: Experiences from *Jangal Mahals* of West Bengal, India

Giyasuddin Siddique, Zeeshan Faiez Siddique, and Livleen Kahlon

Abstract Biodiversity is a manifestation of an ecological system specific to a geographical region and shapes the social systems established and pursued by the human community rooted in that region. Biodiversity is thus deeply embedded in the material, social, and even spiritual perceptions of people sharing a particular ecosystem. West Bengal, though is predominantly a region of mono-crop culture growing rice, is endowed with several subregions rich in biodiversity. These are the wetlands of riparian, estuarine, and coastal areas, foothill forest area of the north, mangrove forest area of the deltaic south, and the deciduous forest area of the southwest plateau-fringe districts. The last one among them is unique in a sense that the indigenous species of plants and animals have been the basis of social systems followed for long by a number of tribal communities. The ecological systems interactive therein are protective to the unique social system of the "first people," and the social systems enriched with "traditional ecological knowledge" are equally protective to the ecology and biodiversity. An integration of administrative, judicial, economic, and social systems formed of traditional ecological knowledge can conserve forest and biodiversity. This paper is an endeavor to explore the chances of conservation of forest and diversity in a combined management system. Analyses have been made with field-based primary and secondary data available for the last five decades; methodology includes qualitative, quantitative, and remote sensing techniques.

Keywords Biodiversity · Ecological system · Indigenous species · Social system · Traditional ecological knowledge · Tribal communities

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5.1 Introduction

Ecological system of a space incorporates the soil system, the vegetation or floral system, and the animal or faunal system; the human community is a component as well as the principal recipient of the energy. The more the number and diversity of species present in those systems, more choices of nutrition and foundation the recipients enjoy of their social systems. In this context, biodiversity is the agency regulating the functions of the physical ecological systems and simultaneously functions as the base of the social ecology by attaching human community. This is truer evident among the community adapted to and reliant upon the productivity of their preferred ecosystem used with traditional knowledge of resource use. These communities in other words are distinguished as “ecosystem people” (Hart 1984) who maintain their livelihood within the boundaries of the ecosystem regions and exist in nearly pristine landscapes where the environment is less modified. The ecosystem people have instituted social systems that are synchronized with the specific elements of the ecosystem and hence concerned to conserve biodiversity.

“Ecosystem people” indigenous communities conserve traditional knowledge that has evolved over generations and is ancestrally inherited. This knowledge has foundationally shaped the cultural values and the social capital of the communities having unique experiences and pragmatic links with their ecosystems (Roué and Nakashima 2002). Berkes et al. (2000) claim that indigenous populations possess a wide range of knowledge about resources that are specific to the local ecosystem. They have developed a singular approach to ecosystem processes and functions. Bettencourt and Kaur (2011) postulate this process as traditional ethnoecology based on a system balanced on two pillars—ecology and anthropology. Studying biodiversity and community interactions, by coalescing traditional and scientific methods, allows new opportunities to adapt diverse sets of management practices. However, a new concept gaining momentum in the last quarter of the twentieth century and the first decade of the twenty-first century is biocultural diversity (BCD). It is a heterogeneous idea addressing the diversity of languages, culture, and life forms that necessitates the recognition of human cultures and languages as an integral part of the diversity of flora, fauna, habitats, and ecosystems. Such an understanding of biocultural diversity helps infer how various elements interact and affect each other in complex ways (Maffi 2005) projecting evolutionary trends through active interactions between humans and nature.

A social system is a patterned network of relationships constituting a coherent whole. According to the social system of the forest dwelling indigenous people, all the living and nonliving objects are integrated within its sphere. Their social system has a great role in determining the norms and beliefs of the human community living in a distinct ecosystem. The community institutionalizes the behavioral approaches toward the objects that they are in frequent contact with. For millennia, the interactions between them and the natural world have formed traditional ecological knowledge which has been preserved by these communities to protect and benefit one another as a rule of live and let live. The community activities constructed by the social systems of traditional ecological knowledge are frequently manifested in their actions of saving the ecosystem (Kala 2011a, b). Therefore, such social systems have assured the restoration of the ecosystem and survival of the life forms inclusive of the forest dwelling tribal community, instead the system being beneficial for interdependence. The interconnectedness of the community of people and the ecology remains strongly influential upon social systems (Hart 1984) driven by and enriched with traditional ecological knowledge helpful to form distinctive worldview (LaDuke 1994). Such worldviews accommodate the exigency and intrinsic values of all the organisms as parts of the ecosystem. In an integrative sense, ecology entails mutual relations between the natural bases and the lives contingent upon them.

The practices of social systems foundationally derived from traditional ecological knowledge can be universally recognized, especially in India which is home to a plethora of ecological communities of tribal origin. India has a rich "tribal" history. Tribes in India are also called *Adivasis*, meaning the earliest settlers. The cultural ideas of these communities have been shaped by ecological knowledge and wisdom, pressing the need of sustainable practices associated with their religious beliefs and culture, evolved in a specific ecosystem/s of a landscape (Swain 2011). India is home to the second largest tribal population in the world after Africa. Over 700 tribes have been consolidated under Article 342 of the Constitution of India. Out of the total rural population in India, 10.4% is tribal population (Census of India 2001). These tribes are usually confined in their geographical pockets and speak their own language. *Gonds*, *Bhils*, *Oranos*, *Santals*, and *Minas* are some of the important tribes in India. Andamans and Nicobar Islands have a mixed population of *Onges*, *Jarawas*, *Sompens*, *Santanelese*, and *Great Andamanese*. To be able to fully construct the tribal history of India, it is important to understand the original ancestors of the current tribal population of India. The earliest inhabitants of peninsular India are the Negritos (Bhasin 2017). Tribes living in Assam, Meghalaya, Mizoram, Nagaland, and Manipur owe their inheritance to the Mongoloid clans. The remaining bulk of the tribal population are known as Dravidians whose origin is from the Mediterranean region. The Dravidian population exists densely over the parts of Peninsular India. Due to a long period of struggle, these tribal populations lived in stress periods. In order to maintain their identity, they finally settled down in remote hills and forests as their areas of inhabitation and are considered as the forefathers of the current tribes in India.

The indigenous tribal groups have settled in several areas of India since the antediluvian past and have maintained their metabolic and material needs from their preferred ecosystems. Their ultimate habitats have mostly been the upland forested zones or the complex hill-plateau-forest regions. These oldest inhabitants caused insignificant harm to nature, by keeping themselves in the role of responsible stewards. Their wisdom of interaction with the natural system for millennia has shaped their beliefs, reflected on their social systems intercepting every object of their distinct habitat.

These indigenous communities across the globe are now minorities and marginalized (Guzy and Kaparo 2018). These communities have mostly settled in the relatively rural terrains that are remote and inaccessible for the people who are settled in urban sectors and adapted to high carbon culture. These nature worshipers have articulated systems that compile all members of the group and pass on to generations (Sponsel 2012). The concept of common property—land, water, and forest—remained isolated only within their established social systems. Eventually, the concept became vulnerable to the market economy imposed by the colonial rulers and then carried forward by the post-independent neoliberal governments. In India, this was accentuated through various Policies and Acts framed and implemented by the authoritarian administrative system. Series of protests and revolts were repeatedly staged by various groups of those forest-based tribal communities joined by other organizations, against the non-tribal entrants and rulers since colonial time.

Discourses on the worldview of tribal groups towards nature and the life system have invited global attention to the knowledge system developed by those groups for millennia. The wisdom of such social groups on use of the natural resources for endurance without any harm to ecology has attracted the current scientific world to comprehend the ways they instituted ecosystems they banked upon (Staff 2018). Knowledge and worldview of indigenous and tribal people on ecology, ecosystem, life, and conservation on local and global perspectives have initiated one of the current fields of research in biological and social sciences (Palmer 1996). It spins around the comprehension of the ideas and practices to protect and conserve the typical ecologies they have adapted for thousands of years. The phrase for marking the insight "ecological knowledge" (Reo 2011) is sought from "indigenous"/ 'traditional" (Taylor 2005), the tribal people in fact, who has sustained generations for thousands of years with minimum demand and maintaining the health of ecosystems (Redfield 1952). The present industrial nations, who consume resources and pollute the environment more than their developing counterparts, now tend to regard the worldview of the tribal people centering on the protection of the environment.

The abodes of the indigenous groups are sometimes visited by the urban folks as places of leisure but remain unaware of the belief system and worldview of the local people who have maintained the ecosystem with their traditional commensalism (Mishra 2009). Even the very nucleus of the latest philosophical approach to ecology like Gaianism, Deep Ecology, and the knowledge of Spiritual Ecology has intricately addressed the worldview possessed by the indigenous people (Sponsel 2012) scattered in remote places.

The ecosystem communities perform, perceive, and explain in specific ways the natural phenomenon, social and cultural events, and relationships within themselves and outside. They manifest their concepts on diverse aspects of life referred to as "worldview," in other sense "mental appreciation of reality" (Sire 2009). It is further expressed not only in their belief but also among their customs, rituals, and actions to believe intricately linked between the beliefs and the contexts that arise. The concept of worldview subsumes both scientific and the ontological perceptions, which might be pragmatic (Tsosie 1996). However, they instill their faith in the code of internal self-determination, inclusive of respecting the customary rights, resources to sustain, and their own sociocultural practices.

Traditionally, the tribal societies practice and enjoy festivities and rituals that are closely linked with natural resources and have evolved over a period of time in particular landscapes. Biocultural knowledge recognizes the interlinks between culture and biodiversity. Wherever there is evidence of inter-mixing of tribes with other members of the society, instances of social assimilation are observed. There are festivals central to indigenous populations and those that were celebrated by members of rural communities and general castes. The festivals of the indigenous tribes were linked to forests, because the inhabitants directly depend on them for meeting their daily requirements. The villagers have a strong belief that these festivals, which they have inherited from their ancestors and are continuing to do, will also protect them from any harm. A few species of plants are regular part of the rituals and cultural festivities observed by many tribal societies including mango (*Mangifera indica*), rajkusumo (), genda (*Tagetes erecta*), muchkundu (*Pterospermum acerifolium*), barh (*Ficus benghalensis*), hambu, limbo (*Azadirachta indica*), and palasho (*Butea monosperma*). Collective knowledge of mixed population groups has led to an increase in observance of cultural practices.

Most of the festivals of the forest dwelling tribal groups put either a nonliving or living entity at the center. They honor the mountains with a faith that it shelters and protects them; worship plants from which they receive food, fodder, and fuel; and share the hills with other animals of various species. The totems and taboos they follow are purposeful to preserve or protect plants or animals (Murugesan 2014), and these will be elaborated with their relevance of biodiversity conservation in the relevant chapters. In a nutshell, the study will reveal that the social systems rooted in the forest dwelling tribal society rich in traditional ecological knowledge possess significant potentiality of biodiversity conservation of the area under review. This paper is an endeavor to analyze the importance of the social systems and based upon the beliefs and worldview of the indigenous forest dwelling tribal people equipped with traditional ecological knowledge in conservation of ecosystem and its biodiversity.

It seems essential to mention that the abodes and bioregions not only inhabited first by the older indigenous tribal groups were colonized by the Western and the Northern Whites through weapons of enlightenment, industrial revolution, market economy, and technocentrism but colonized the non-white indigenous communities too (Nadasdy 2005). They were not merely uprooted from their ecosystems, but their traditional knowledge on nature, belief system, and eco-friendly simple life bases and worldviews enveloped in their customs and rituals were disrupted and marginalized (Nadasdy 1999). Until recently, it is evident that to retard the present ecological crises can be learnt from the worldview on ecological system developed by the tribal groups scattered mostly in various corners of the old world like Cree Indians of North America, Cherokees of the SE USA, Tribes of Australia, the Gonds, the Bhils, the Baigas, the Mundas, the Sabars, the Birhors, the Santals, and a number of other groups of India (Table 5.1).

The aboriginal tribal communities rooted in the densely forested southwestern districts of West Bengal, in the recent past known as the Jangal Mahals. These communities were more directly associated with and dependent upon various types

Table 5.1 List of tribes and races in the world

S. no	Tribes and races	Global regions
1.	Abhors	Mongolians living in the Assam region
2.	Afridis	Inhabitants of the northwest frontier in Pakistan
3.	Afrikaner	Dutch-born South African race
4.	Bedouins	Wandering tribe of Arabia and North Africa
5.	Bhils	Ancient Dravidians of central India
6.	Cossacks	Inhabitants of southern and eastern frontiers of Russia
7.	Croats	Inhabitants of Croatia
8.	Dravidians	Ancient people of South India (non-Aryans)
9.	Eskimos	Inhabitants of the Arctic Circle and Greenland
10.	Filipinos	Natives of the Philippines
11.	Flemish	Original inhabitants of Belgium
12.	Garos	Hill tribe of Assam
13.	Gorkhas	Martial race of Nepal
14.	Hottentots	Pastoral nomads of southwest Africa
15.	Kaffris	Martial race of South Africa
16.	Kardars	Descendants of the Austric race, now living in the forests of central and northern India
17.	Khasis	Tribes of Meghalaya
18.	Khirgiz	Tribe living in Central Asia
19.	Kiwis	People of New Zealand
20.	Magyars	Inhabitants of Hungary
21.	Masuds	Tribe living in Waziristan (Pakistan)
22.	Maoris	Natives of New Zealand
23.	Moor	A mixed tribe of Arab and Berber people of Morocco
24.	Blacks	Dark-skinned race of Africa
25.	Nipponese	People living in Japan
26.	Red Indians	Original inhabitants of North America
27.	Sherpas	Tribe on the border of Tibet and Nepal
28.	Slovenes	People living in former Yugoslavia; of Slavic origin
29.	Swahili	People living in parts of Kenya and Tanzania
30.	Todas	Natives of Nilgiri Hills
31.	Zulus	People living in South Africa; belonging to the Bantu family

Source: The above table is finalized as per the data available under the 1991 census (Adapted from https://www.jagranjosh.com/general-knowledge/tribes-and-races-in-the-world)

of plant and animal species of forests for their material, nutritional, and sociocultural requisites (Bhattacharjee 2016). These people living for generations through millennia within or at the periphery of the forests have been known as “Forest People” belonging to tribal communities, and the “Other Traditional Forest Dwellers” not bracketed in tribal entity. Enforced by the market economy introduced by the colonial rulers at the end of the eighteenth century, wanton destruction of forests and extensive land use-land cover change became evident. Consequential soil erosion and gradual degradation of the health of the forest ecosystem in those areas deployed threats to the simple and forest-based living system of those tribal communities.

A series of forest policies framed and implemented in pre- and post-independent India that practically favored the traders and rulers in extracting and sharing economic benefits. However, almost all the policies kept the tribal or forest people out of forests enforcing several Acts and Laws (Siddique 2012). Exploitation made to the forest ecology and the "Forest People" or "ecosystem people" was not as simple as the narrative is. First they lost the source of their nutrition and resources essential for their livelihood; second, they were turned into "ecosystem refugee" by being ousted from or deprived of the forest ecosystem (Hart 1984); and third, they had to bear with silence the difficulty in continuation of various traits of their social systems like festivals, rituals, practices, belief systems, etc., due to absence of a number of species placed at the center of their social systems (Siddique 2020). Their reliance on material including nutritional, fiscal, and social systems, long established by the forest people, helped grow and enrich traditional ecological knowledge which is protective about the forest ecosystem and germane to preservation and conservation of biodiversity (Purshottam and Dhingra 2017). The accumulated traditional ecological knowledge of the forest people gradually constructed their nature-based worldview, which is now prescribed by ecologists for ecosystem conservation.

5.2 Database

The present study is based basically on secondary data, but primary data, facts, and figures also assert equal importance. The database pertinent to the objective of the study has been amassed and generated from repeated field works carried out in some selected CD Blocks of the western districts of West Bengal where the presence of the forests and forest dwelling tribal communities is significantly high in the total population. Oral interactions and group discussions with them have been helpful in receiving and documenting the belief system, social systems, significance of biodiversity in ecosystem, and worldview. The database thus accounts for the appraisals of those people on the present economic, social, medical, spiritual, and political systems effective upon their life and livelihood. The secondary database of the study comprises a number of literatures including novels, research papers, theses, books, records and reports, memoirs, and census handbooks. Assorted websites have helped in realizing the social systems formed and followed by the native people living in various ecologies of different continents. Numerous literary writings on culture and social systems of indigenous people, forest and tribal ecology, post-colonialism, and ecocriticism have been important sources of databases of the present study. Several folk tales, folklore, folk songs, proverbs, and metaphors of different tribal groups have been assorted as sources of information.

5.2.1 Methodology

This study is based on behaviorism, pragmatism, and a holistic environmentalist approach. The discourses have been structured with an empiric and mostly qualitative methodological approach, for quantification of views and beliefs entrenched in social systems, which is seldom rational, rather unrealistic. Information collected from field visits have been analyzed and restructured to arrive at a cogent conclusion.

5.2.2 The Study Area

The area under study comprises the western Districts of West Bengal: Birbhum, Paschim Bardhaman, Bankura, Puruliya, Paschim Medinipur, and Jhargram, altogether known as *Jangal Mahal Districts* (Fig. 5.1). The rationale behind selection of these six districts remains in the sub-humid dry deciduous forest, the distribution and density of which are relatively higher. Also, the percentage of forest land shared by the forest dwelling tribal communities in total population is higher than any other districts of West Bengal. This coexistence is significantly self-convincing that the forests and the tribes have an intricate link to form a distinct ecology and social systems attuned to that ecology.

5.2.3 Geographic Specialty

West Bengal is characterized with three forest belts: the northern Himalayan foothills which are significantly destroyed to accommodate tea gardens since the colonial period; the sub-humid dry deciduous forests in the southwestern plateau-plain fringe area; and the mangrove forest zone of the southeast coastal belt. Among these, the Himalayan foothill forests of the Terai region do not show affinities to the Tibeto-Burmese tribal groups who rather practice terrace cultivation but follow their own culture and belief in which forests have very less sway (Munshi 2012). The mangrove forests of the coastal southern West Bengal are inhabited and not by tribes but people of various castes from ancient times. The people in this particular forest ecosystem are dependent much on aquatic resources compared to forest resources. Historically, the southwestern forested tract is significantly inhabited by a number of tribal communities who have been reliant substantially on the forests (Siddique 2012) for material, social, and spiritual needs, influencing them to develop their own belief systems, social systems, and worldview. Figure 5.2 will be helpful to understand the distribution of forests and tribes and the forest-tribe association in southwestern West Bengal.

Gondwanaland, the ancient landmass of India, is named after the Gond tribe who were the oldest settlers. The Bhils, the Kols, the Mundas, and others are the other

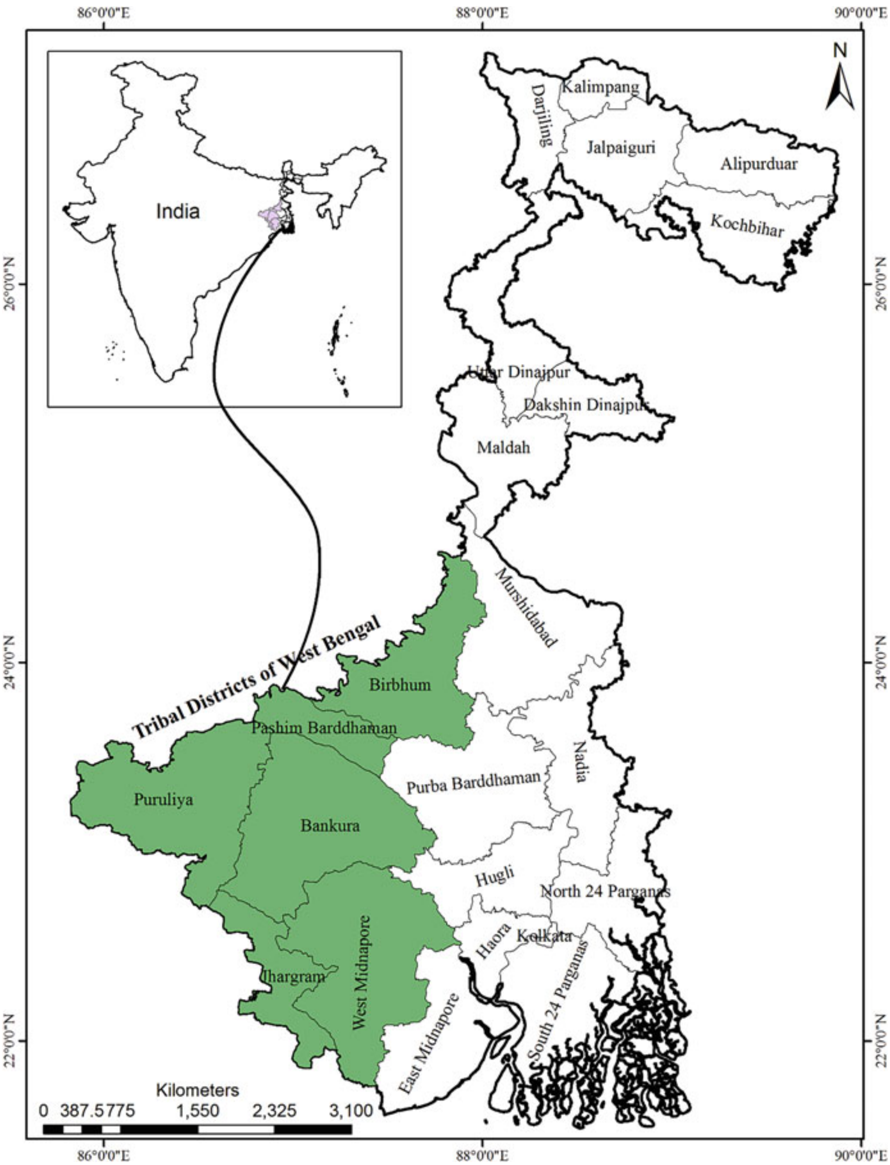

Fig. 5.1 The location of the tribal Districts of West Bengal: Birbhum, Paschim Bardhaman, Bankura, Puruliya, Paschim Medinipur, and Jhargram, altogether known as *Jangal Mahal Districts*

major tribal groups of the same antiquity. Ethnologists from India and other countries have confirmed that the tribal communities of India are the oldest settled people of the Indian subcontinent. India has been ascribed as a "centroid" of the early human prehistory and a series of migration for Anatomically Modern Human

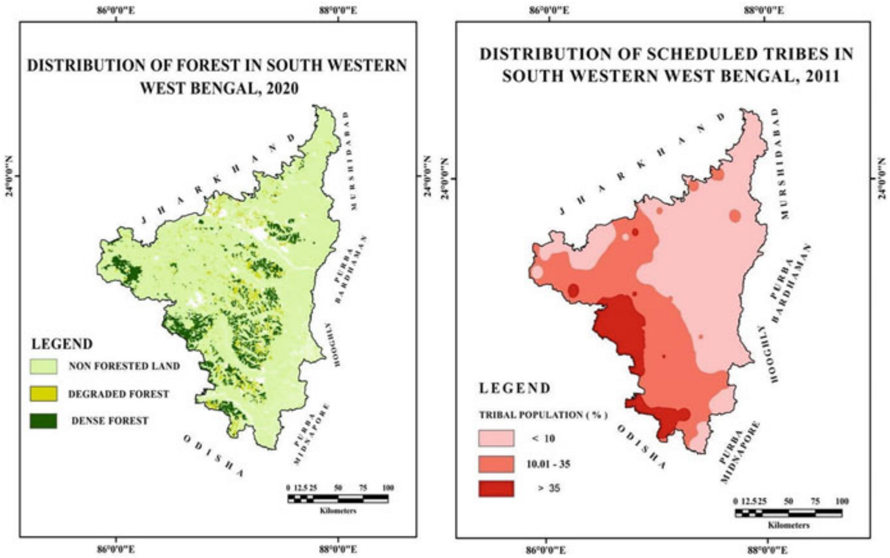

Fig. 5.2 The forest-tribe association of western West Bengal

(AMH) from Africa to Australia during the Late Pleistocene period (Petraglia and Allchin 2007; Borkar et al. 2011). In contemporary science, the lineage of population can be easily traced by associating historic events like migration, linguistic, and archeological data. Human colonization of the Indian subcontinent by tribes and castes representing different genetics provides unique source for the understanding of human evolution (Kivisild et al. 2011; Borkar et al. 2011) in India, and the Mundary-speaking people of the current Jangal Mahal districts of West Bengal are their distant relatives.

5.2.4 The Human Communities

The tribal population of the southwestern West Bengal, partially influenced by Aryan, may rightly be designated as “aboriginals.” The term “aboriginal” does not indicate that they were or are the original autochthones of this land. It implies that these people were non-Aryans, less exposed to admixture of the Aryan blood and culture, which has left its impressions upon the residents of Bengal’s riverine plains (Hunter 1882). With the waves of immigration of different races, most of the tribes in India had been successively pushed on, endangering their existence. The aboriginals currently settled in this tract had followed the same fate (Dalton 1872). The tribes, who first immigrated in this area before a few thousand years, were first pushed on by the Aryanized intruders from the north, and later by the plains’ agriculturists from the east, ultimately outcasted to the rugged plateau-hill forests (Chakraborty 1982).

Table 5.2 District wise Trible population in the selected districts of west Bengal

District	Purulia	Bankura	Jhargram	Paschim Midnapore	Purba Bardhaman	Birbhum
Tribal population (%)	18.40	10.20	30.50	10.90	5.00	6.80

Source: Census Handbook of West Bengal, Census of India 2011

The following tables demonstrate the district level (Table 5.2) and block level (Table 5.3) presence of the tribal people within the area under review. It is important to mention that the sects and groups of the tribal communities could not be placed as such is not readily available and could not be enumerated because of the COVID-19 situation.

The people belonging to the Santal, the Bhumij, the Birhore, the Lodha, etc. communities are pre-Dravidian in physical characteristics like stature, nasal, and cephalic structure, color of the skin, and coarse hair and Austric and Dravidian in linguistic features. But it should be noted that the aboriginals of this area may be grouped into the "forest tribes" (Kol, Santal, Bheels, etc.) and Dravidians (the other tribals and semi-tribals) (Dalton 1872).

The forests and the tribes in this lateritic tract of the southwestern West Bengal has a readily observable association shown in Fig. 5.3. This type of logistical union is hardly present in other forest areas of West Bengal. Various records and analyses shows that the aboriginal tribes in this tract are prone to this area in the long past as they were driven out from the forests of central Indian highlands by the Aryans and Aryanized high-caste people (Dalton 1872) and were also driven back by the plains' agriculturists, toward the plateau-hill-forest complex (Chakraborty 1982). Still now, this tract has retained a considerable forest cover and tribal habitations in several locations, though the original tribal populations were much higher in number in the past. The people in this area now exhibit a variety of associations, beginning from forest-covered hills to the cultivated river valleys, though essentially it was a hill-plateau-forest complex in the past.

5.2.5 Biodiversity as Base of Ecological Systems

Biological diversity or simply biodiversity refers to the diversity of plants and animals, along with other living organisms in a particular area or region. Biodiversity is the totality of the genes, species, and ecosystems in a region (UNEP), which is otherwise defined as a bioregion. Literally and metaphorically, bioregion may be defined in short as "natural countries that cannot be found in Atlas" with "soft borders" which are "populated by native plants and animals that have endured since the last Ice Age" (Clark et al. 2018). Everything that lives in an ecosystem is part of the web of life, including humans which altogether constitutes the foundation of a bioregion. Each species of vegetation and each creature of an ecosystem has a place

Table 5.3 Community development block wise Trible population in the study area

District	CD BLOCK	TOTAL_POP	TRIBAL_POP	%
Jhargram	BINPUR-2	164,522	65,722	39.95
	BINPUR-1	156,153	43,962	28.15
	JAMBONI	113,197	32,369	28.60
	JHARGRAM	170,097	38,625	22.71
	GOPIBALLAVPUR-2	104,996	24,562	23.40
	SANKRAIL	115,418	28,825	24.97
	GOPIBALLAVPUR-1	108,254	36,819	34.01
	NAYAGRAM	142,199	56,887	40.00
Purulia	JHALDA-1	137,143	15,608	11.38
	JHALDA-2	148,156	18,917	12.77
	BAGHMUNDI	135,579	34,038	25.11
	ARSHA	154,736	33,568	21.69
	JOYPUR	133,349	13,074	9.80
	PURULIYA-1	151,188	12,655	8.37
	BALARAMPUR	137,950	43,738	31.71
	PURULIYA-2	169,488	8213	4.85
	BARABAZAR	170,564	33,096	19.40
	PARA	200,621	10,335	5.15
	RAGHUNATHPUR-2	113,790	7302	6.42
	NETURIA	101,427	22,616	22.30
	SANTURI	78,515	25,083	31.95
	RAGHUNATHPUR-1	117,760	12,599	10.70
	KASHIPUR	200,083	49,537	24.76
	HURA	143,575	36,561	25.46
	PUNCHA	123,855	30,641	24.74
	MANBAZAR-1	154,071	33,942	22.03
	MANBAZAR-2	97,164	47,580	48.97
	BANDWAN	94,929	49,232	51.86
Paschim Medinipur	GARHBETA-2	148,410	29,669	19.99
	SALBONI	188,653	32,771	17.37
	MIDNAPORE	191,705	33,869	17.67
	KHARGAPUR-1	258,040	42,453	16.45
	KESHIARY	149,260	51,128	34.25
	DANTAN-1	172,107	28,183	16.38
	MOHANPUR	111,901	6026	5.39
	DANTAN-2	155,017	10,861	7.01
	NARAYANGARH	302,620	68,080	22.50
	SABONG	270,492	16,818	6.22
	PINGLA	194,809	19,332	9.92
	DEBRA	288,619	59,122	20.48
	DASPUR-2	238,529	585	0.25
	DASPUR-1	203,987	5695	2.79

(continued)

Table 5.3 (continued)

District	CD BLOCK	TOTAL_POP	TRIBAL_POP	%
	GHATAL	219,555	3861	1.76
	CHANDRAKONA-1	136,006	7516	5.53
	GARHBETA-1	228,513	18,134	7.94
	GARBETA-3	169,528	23,955	14.13
	CHANDRAKANA-2	123,269	6841	5.55
	KESHPUR	339,248	19,616	5.78
	KHARGAPUR-2	183,440	46,899	25.57

Source: Census Handbook of West Bengal, Census of India 2011

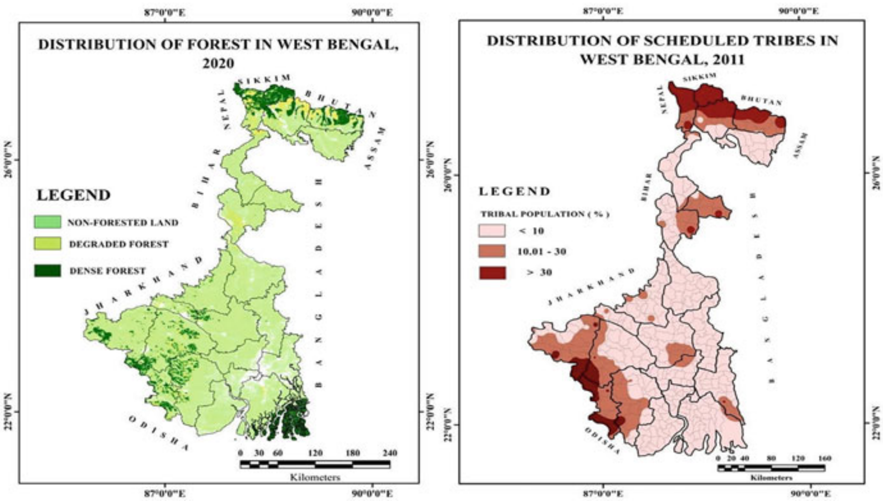

Fig. 5.3 Distribution of forest cover and scheduled tribes in west Bengal

in it and plays a vital role in the circle of life in totality. Plant, animal, microbes, and insect species together interact and depend upon one another for what each offers, such as food, shelter, oxygen, and soil enrichment. Any substantial break in the chain of interaction enforces metabolic rift. Reduction or extermination of species diversity in a bioregion ultimately invites threat to humanity itself, primarily to the local people. This was perceived and experienced by the indigenous tribal communities, who are reliant upon distinct ecosystems and whose social systems were attuned with that natural system. The energy produced by green vegetation is received by animals which clung at distinct trophic levels in accordance with the second law of thermodynamics; the energy pyramid determines the number pyramid (Kormondy 1976). The forest ecosystems of tropical belts like the forests of the area under review are productive ecosystems having the capacity to support a large range of diverse species from grazing animals to avifauna. All forest ecosystems are essentially biodiversity hotspots where green vegetation forms the base of the system

(Odum 1971). The tribal forest dwellers are just a community of consumers of excess energy of all trophic levels. However, it is important to mention that innumerable trees, shrubs, herbs, and succulents form the bases of the ecosystem.

5.2.6 Biodiversity as Base of Social Systems

It has been mentioned earlier that the social system is a patterned network of relationships constituting a coherent whole. The social systems of the forest dwelling tribal people ensemble all the living and nonliving objects of an ecosystem. They live within or at the periphery of the boundary of the forest ecosystem as their distant forefathers continued doing for centuries (Guha 1988). Never have they lived resource-intensive life, but been experts of a narrow energy balance. They have developed a belief system in social life that their life will sustain, only if the forests do sustain without degradation and deforestation (Gadgil and Guha 1995). They were well aware about the health of the forest vegetation and learnt a lot on the growth, propagation, and even disease of the forest trees as well their care for. The basic material needs like shelter, food, fiber, fodder, and fire were all met up with forest produce. Therefore, their social, fiscal, political (Alier 2014), and spiritual lives revolved around forest as they either collect or produce their nutrition and needs from forests at different seasons. Forests supply them all kinds of necessary nutrients at the time of crisis, and generally they do not have to starve who knows well the plants that produce bulbs or edible roots. They have vivid knowledge in replenishment of soil fertility without application of chemical fertilizer and never go for chemical pesticides.

They have devised a number of norms in their social system which commends the need to protect, save, and thrive various lives—plants and animals—the purpose being conservation and regeneration of species and restoration of habitat. The knowledge on nature and life systems they have accumulated by generation is acknowledged as traditional ecological knowledge which has enriched their social systems (Kala 2013). Different norms prescribed by the social system in turn have been beneficial to conserve biodiversity. For example, the sites of sacred groves where the souls of their ancestors reside, as they believe, have conserved a plethora of plants, especially medicinal plant species.

The tribal people dependent upon wild species of fruits, seeds, bulbs, roots, and tubers, used for edible purposes is a way of conservation and such activities protect biodiversity.

Tribal communities follow the laws of conservation in harvesting edible plants which ascertain ecological care. Fruits of edible plants like those of *Dioscorea* spp. are harvested only when they become mature (Rai and Nath 2013). The wild tubers from the forest floor are dug out carefully, saving the associated species. Such activities are normal, rather than practical, and helpful to species conservation (Tables 5.4 and 5.5).

Table 5.4 Tribal communities and the harvesting edible plants in the study area

Scientific name	Local name	Family name	Uses	As per POWO
Aegle marmelos	Bel	Rutaceae	Fruits are roasted and eaten	*Aegle marmelos* (L.) Correa
Amorphophallus paenonflodium	Suran	Araceae	Petiole/bulb as vegetable	Not found
Achyranthes aspera L.	Chirchita	Amaranthaceae	Tender shoots as vegetable	*Achyranthes asper* L.
Bauhinia purpurea	Keolar bhaji	Convolvulaceae	Leaves, flowers, seeds as vegetable	*Bauhinia purpurea* L.
Bauhinia vahlii	Sehar	Caesalpiniaceae	Leaves as vegetable	*Bauhinia vahlii* Wight and Arn.
Dioscorea alata	Dudhia aru	Dioscoreaceae	Tubers as Vegetable	*Dioscorea alata* L.
Curculigo orchioides	Kali musli	Amaryllidaceae	Roots and Tubers as vegetable	*Curculigo orchioides* Gaertn.
Xylia xylocarpa	Jambu	Mimosaceae	Seeds as vegetable	*Xylia xylocarpa (Roxb.) W.Theob*
Entada pursaetha		Mimosaceae	Seeds as vegetable	*Entada pursaetha D.C.*
Dioscorea bulbifera	Ratalu	Dioscoreaceae	Tubers as vegetable	*Dioscorea bulbifera* L.

Source: Rajiv Rai and Vijendra Nath (Rai and Nath 2013)

Table 5.5 Plants growing in sacred groves in India

S. no	Name of plant	Uses	Scientific name
1	*Butea monosperma*	Medicinal, Dye	*Butea monosperma* (Lam.) Kuntze
2.	*Cordia dichotoma*	Food, Medicinal	*Cordia dichotoma* (Ruiz & Pav.)
3.	*Rauvolfia serpentina*	Medicinal	*Rauvolfia serpentina* (L.) Benth. ex Kurz
4.	*Alstonia scholaris*	Medicinal	*Alstonia scholaris* (L.) R.Br.
5.	*Helicteres isora*	Medicinal	*Helicteres isora* L.
6.	*Boswellia serrata*	Medicinal	*Boswellia serrata* Roxb.
7.	*Calotropis gigantea*	Medicinal	*Calotropis gigantea* (L.) W.T. Aiton
8.	*Carissa congesta*	Medicinal	*Carissa congesta* Wight
9.	*Diospyros montana*	Medicinal	*Not found*
10.	*Bambusa arundinacea* (wild bamboo)	Miscellaneous	(Retz.) Willd

Source: Jain, S.K. Ethnobiology in Human welfare

Being determined and equipped with social norms and activities, management, extension, and re-stabilization of forest cover and forest ecosystems have been realized in Jhargram District, which has visually extended its services to the forest dwellers. However, more importance needs to be given on the use of the traditional knowledge of the forest dwellers to care for the health of the forest ecosystem through regeneration and restoration of the indigenous tree species of the forest with its natural fervor. The participation of forest dwellers equipped with such knowledge helps maintain the balance of the forest ecosystem and also strengthens the efficiency of the forest management system (Gupta 2016). These ecosystems establish and follow symbiotic relationships of plants, wild animals, and forest dwellers. Thus, the traditional knowledge of forest dwellers has been essential for the sustainable conservation of forests (Parotta et al. 2016). Forests have a direct role in protecting soil from erosion, increasing soil fertility with addition of humus, and maintaining micro-climatic situations by controlling local temperature. The destruction and overuse of forest ecosystems have been directly detrimental to the livelihood of forest dwellers of the districts under study (Atrayee and Choudhury 2013). Emphasizing and linking social values and proper conservation of forest and animal species may further be improved by adding together the traditional knowledge of the indigenous forest dwellers.

The SWOT analysis focusing the ecosystem services rendered by the forest ecosystem of the area to the forest dwellers is self-explanatory that it embraces the group priority factors that actually involve direct links to the social, fiscal, societal, and political questions. Exploration of the avenues for minimizing the threats and maximizing the opportunities cannot circumvent the society and the social customs, beliefs, worldview, festivals, and rituals—all insist on the social system.

The analysis has been made based on the data and information collected from five forest patches located in four blocks of the Jhargram District of West Bengal. The combined process of SWOT-AHP [analytical hierarchy process] is usually accomplished through three functional steps. *The first step* identifies the four main components (**strengths, weaknesses, potentials, threats**) of SWOT analysis. *The Second step* using the **pairwise fundamental scale** developed by Wind and Saaty (1980), compares the parallels between each section of the SWOT analysis (Tables 5.6 and 5.7), and the method is that if attribute **S1** is absolutely more important than attribute **S2** and is rated at **3**, then **S2** must be absolutely less important than **S1**. And **S1** Value is **3** and **S2** is valued is **1/3**. The value of another factor is determined based on the relative importance of one factor for comparisons (Table 5.8).

The values concentrated in the NW quarter of the diagram represent Opportunities; similarly the NE quarter highlights Strength, the SW quarter signifies Weakness, and the SE quarter denotes the Threats. It may be recommended that the varieties of weaknesses and the threats may gradually be eliminated or at least minimized through restoration and conservation of preferred species that renders

Table 5.6 Pairwise fundamental scale for comparison

Magnitude of importance	Definition	Explanation
1	Equivalent importance	Two factors contribute equally to the objectives
2	Weak	Experience and judgment
3	Moderate importance	Slightly favor one activity one another
4	Moderate plus	Experience and judgment
5	Strong importance	Strongly favor one activity one another
6	Strong plus	An activity is favored very
7	Very strong and demonstrated	Strongly favor, and its dominance is demonstrated in practice
8	Very, very strong	The evidence favoring one
9	Excessive importance	Importance of one over another affirmed on the highest possible order

Comparison scale (Adapted from Wind and Saaty (1980), Birendra (2014))

Table 5.7 Comparisons scale of SWOT factors

SWOT groups	Strength	Weakness	Opportunities	Threats	Group priority of SWOT categories
Strength (S)	1.000	3.000	1.000	5.000	–
Weakness (W)	1/3	1.000	1/4	2.000	–
Opportunities (O)	1.000	4.000	1.000	2.000	–
Threats (T)	1/5	1/2	1/2	1.000	–
SWOT groups	Strength	Weakness	Opportunities	Threats	Group priority of SWOT categories
Strength (S)	1.000	3.000	1.000	5.000	**0.421**
Weakness (W)	0.333	1.000	0.250	2.000	0.151
Opportunities (O)	1.000	4.000	1.000	2.000	0.336
Threats (T)	0.200	0.500	0.500	1.000	0.093

Strength = 1 + 3 + 1 + 5 = **10**, Weakness = 0.333 + 1 + 0.250 + 2 = **3.583**, Opportunities = 1 + 4 + 1 + 2 = **8**, Threats = 0.200 + 0.500 + 0.500 + 1.00 = **2.2**
Sum of SWOT group is 10 + 3.580 + 8 + 2.2 = **23.783**
Group priority of **strength (S)** categories is **10/23.783 = 0.421**
The values of the other three categories will come out in the same way

single- or multiple-ecosystem service (Fig. 5.4). In most cases, these are achieved through participation of the local beneficiaries, habitually the local tribal dwellers equipped with traditional ecological knowledge even passed on to their social norms and traits like festivals, rituals, etc.

Table 5.8 SWOT factors overall priority scores for the ecosystem service framework of Jhargram District

SWOT group	Group priority	Factors of group priority (SWOT)	Priority factor within the group	Overall priority factor
Strength	0.421	(S_1) Coexistence of forest people	0.208	0.088
		(S_2) Social and cultural values of forest dwellers	0.199	0.084
		(S_3) Worship of trees as a religious institution of forest dwellers	0.385	0.162
		(S_4) Use of traditional knowledge for forest management by forest dwellers	0.114	0.048
		(S_5) Sustainable use of timber and non-timber forest resources	0.094	0.040
Weakness	0.151	(W_1) Efforts to reduce the rights of forest dwellers	0.209	0.034
		(W_2) Widespread poverty in the STs and OTFDs Communities	0.249	0.038
		(W_3) Use of forest resources by the government for commercial use	0.110	0.017
		(W_4) Decreased power to access forest production for forest dwellers	0.265	0.040
		(W_5) Traditional knowledge of forest resources of STs and OTFDs is not used	0.166	0.025
Opportunities	0.336	(O_1) Increasing reforestation activities by the use of traditional knowledge of forest dwellers	0.240	0.081
		(O_2) To recognize the coexistence of forests and forest dwellers	0.091	0.031
		(O_3) Improving the socioeconomic status of forest dwellers	0.240	0.081
		(O_4) Participation of forest dwellers in improving eco-tourism development	0.189	0.064
		(O_5) Use of participatory management in conservation of forest resources	0.240	0.081
Threats	0.093	(T_1) Illegal exploitation of forest resources by exogenesis people	0.150	0.014
		(T_2) Loss of biodiversity	0.100	0.009
		(T_3) Lack of lucid discussion on forest right of forest dwellers in the forest policy	0.250	0.023
		(T_4) Control of collection of dried wood from the forest	0.300	0.028
		(T_5) Political instability	0.200	0.019

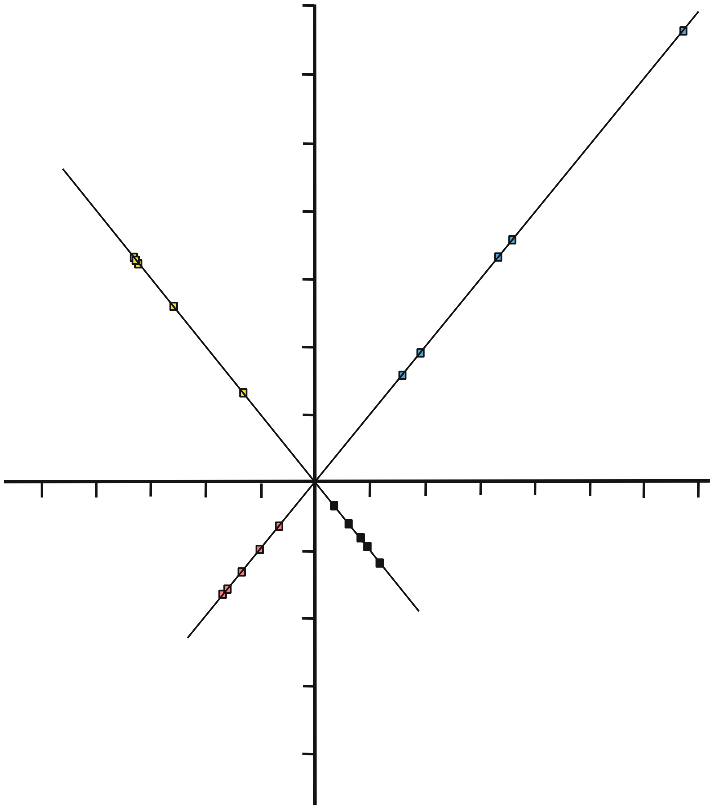

Fig. 5.4 Graphical representation of the model with factor and value more clearly reveals the forest-people relationship in the Jhargram District

5.2.7 Forces and Factors of Biodiversity Depletion

Our planet is losing numbers of biodiversity in every moment, and several species of plants and animals are either becoming extinct, endangered, or facing threats. The region under review is accruing similar experiences because of certain forces and factors. Here, the natural processes, mainly related to climatic shifts, and seasonal temperature extremities are deemed as factors of depletion. In reality, the pre-and post-independence revenues and forest policies combined with market economy need to be reckoned as forces of biodiversity depletion facilitated by forces of deforestation. However, the forest people or the tribal residents who are never part of it have been successful in conserving a number of species (Pallavi 2015).

Threats to biodiversity are largely caused by:

- Habitat destruction: Is enforced with both public and private organizations, though the public concern is more powerful involving mainly infrastructure development—like extension of transport corridors, setting up industrial units, dam building, etc. that obliterates a large forest area. A number of dams built in the area under the management of Damodar Valley Corporation (DVC) may be mentioned.

- Overharvesting of local species: Demand of indigenous vegetable and animal products within and outside the area impacts the supply by causing overharvesting which leads to threat.
- Overexploitation and non-replenishment of soil nutrients: Reduction in area increases the density of species pressing upon the demands of nutrients of soil of a limited area, and disruption of the nutrient cycles invites metabolic rift for other species in the same food chain, ultimately causing degradation of the ecosystem and retardation of species.
- Climatic uncertainty: Irregular or scanty rainfall and prolonged dry spells sometimes harm the growth and health of local species.
- Displacement of native species and invasion of exotic species: The regional ecosystem and the material needs of the local people attached to that ecosystem are mainly reliant upon the indigenous plants and animal species. Invasion of exotic varieties of plants causes harm to the ecosystem and food chain.
- Associated social and economic conditions: The rural tribal communities especially those who are dwelling in and around the forested tracts are essentially economically poor and socially marginal. The forests in India from the colonial to the present times have been managed by the people who lived outside the forest regime; the policies and acts of forests passed by the non-tribal rulers have always excluded the tribal people who are protective about forests and reliant upon the energy excess of forest ecosystem—the minor forest produce. As a consequence, fragmentation of forest habitats, degradation of forest, despeciation, and deforestation are gradually occurring.

5.2.8 Social System, Norms, and Customs as Forces of Biodiversity Conservation

The belief systems and worldview of the forest dwelling tribal groups nowadays needed to be reviewed with ecological and sociopolitical connotation. Each species of the forest ecosystem is viewed as an indivisible entity together forming the unified whole which is a common resource pool for the members only; matter or energy excess of the ecosystem may be taken out of the ecosystem boundary. Thus, they have developed certain norms, customs, etc. to protect and conserve all the plant and animal species (Kala 2011a, b) in their ecosystem that they belong to. Some of the unique social group or community activities in the form of festivals have helped understand the importance of a single species and its conservation. For example:

1. **Karam Puja**: A festival followed by the tribal communities of Chhattisgarh, Bihar, Jharkhand, Odisha, and West Bengal. This festival is celebrated for a good harvest of local traditional cereal, seeds, and legumes. The ecosystem people visit

the jungle accompanied by groups of drummers and cut one or more branches of the Karam tree (*Neolamarckia cadamba*). After worshiping, the branches are brought to the village. Thus, it conserves indigenous vegetation species, the patch of forest housing the vegetation and the cultivators. The reality is the festival indirectly facilitates the conservation of local genetic resources.

2. They believe that the dense old forest patches or original dense groves contiguous to or reside beside their hamlets are the abodes of their predecessors; thus, these are "sacred" and honored as "sacred groves." Such types of groves, one or more, are rooted almost in each village. These certainly are the sites that embrace in situ conservation of local biodiversity playing the role of small biodiversity hotspots. Even these provide shelter to a number of rare birds, lizards, insects, and medicinal herbs.
3. A number of higher trees like *Shorea robusta*, *Schleichera oleosa*, and *Terminalia elliptica* have special importance in the cultural practices of the tribal communities. They oppose cutting of these trees and worship them. Especially *Shorea robusta* is connected with their economic and social life. They use its leaves for making wrappers and plates, while its flower is used for natural aroma and resins as insect repellent. Beyond such traditional knowledge, the tribal communities have special honor to this climax species in their mind and are always in favor of its conservation. Liquor from flowers and oil from the seeds of *Madhuca longifolia* have importance in the social life of the tribal communities. Different rituals are protective to different tree species.
4. In general, the tribal communities are nature worshipers, and some taboos followed by these communities have helped conservation of a number of species that are not allowed to kill and consume. Based on their belief and practice, they usually do not kill snakes. Some lizards are on their diet list but do no harm to them unless they are compelled to do so, rather utter repentance before they kill a life.
5. Based on their belief system and rich traditional ecological knowledge, they have developed therapeutic healthcare and disease control methods with application of medicinal plants, herbs, and lianas. Use and offerings of a number of leaves and flowers in various festivals and rituals as part of their customs have helped preservation of plants and herbs, those plants even unknown to common people.

5.3 Conclusion

Human society, from the stage of its emergence, has been associated with other species for its survival and progress. The forest-dwelling tribal communities still prefer the affinity of forest not for their habitual livelihood, rather than the forests and its innumerable plants and animal communities are living unharmed because of the presence of those tribal people in and around the forests. Their social system, customs, and rituals are oriented to the conservation of all lives sharing the forest ecosystem. Their belief system, worldview, moral, and societal life have blended together as traditional ecological knowledge that always works for coexistence of all species—presence of forest species has become synonymous with presence of resident forest people. Inclusion of those people in the forest protection committees has been proved with the forest health of various forest belts West Bengal, as well as of India.

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Chapter 6
'Green Placemaking' in Kolkata: Role of Urban Greens and Urban Forestry

Anindya Basu, Lopamudra Bakshi Basu, Vasco Barbosa, and Hashem Dadashpoor

Abstract Widespread urbanisation has depleted green cover increasing vulnerability to climate change, especially in the developing countries with India being no exception. While a handful of cities have been able to come up with integrated urban greenery provisions; the megalopolis of Kolkata having rich colonial legacy have failed to hold on to its green spaces due to rampant urbanisation waves. Urban greens and urban forestry are probable ways to bridge the gap between city dwellers and their much-needed greenery, which has now been actively taken up by the governmental agencies. But urban greenery development relies largely on the attitude and involvement of urban residents. The apt species selection for plantation in the heavily built-up milieu is lacking in the city. Kolkata is trying hard to have its desired share of man-made urban forest through the sprawling greens of over 7 acres, in New Town Rajarhat-east Kolkata, mirroring the centralised 'Nagar Van' scheme. This paper attempts to describe the global, national urban green scenario and specifically concentrates on Kolkata's Urban Green Spaces (UGS) through preparation of tree-inventory, analytical study of spatio-temporal changing green cover with the help of land use and land cover (LULC), Normalized Vegetation Index (NDVI) and Enhanced Vegetation Index (EVI) analysis from LANDSAT imageries. The indices clearly show the declining trend of the green cover (1980–2020), and the regression analysis of NDVI and land surface temperature (LST) shows a strong negative correlation. After investigating the loopholes in arboricultural practices,

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zones for peri-urban forest development have been chalked out. The perception studies of urban dwellers about the diverse role of urban forestry bring out that the residents are aware of the dire need to protect the green and have been taking part in developing the green spaces in the city.

Keywords Green cover · Species selection · Urban Green Spaces (UGS) · Urban forestry · Arboricultural practices

6.1 Introduction

In the era of global climate change and rapid urbanisation, innovations in the urban system are a critical requirement for tackling the serious environmental challenges it is facing. It is foreseeable that almost two thirds of the world's population will live in the urban areas by 2025 (Schell and Ulijaszek 1999). In the developed countries, presently, most of the population dwells in the cities, like more than 80% of the USA (Wolf 1998) and about 85% of Australia (Brack 2002) are urbanised. On the other hand, in the developing countries, about 44% of the population currently resides in urban areas and is likely to increase sharply over a span of a decade (UN-Habitat 2009; Montgomery 2008). Rapid urbanisation in India has brought complex changes to ecology, economy and society (DeFries and Pandey 2010). Urban greenery and forestry are one of the possible ways to bridge the gap between the people and their environment. Numerous policy instruments over the past two decades have stressed the critical requirement of the green zones within the urban socio-ecological systems to address several problems related to city living. Urbanisation, a human-induced process, refers to the gradual alteration in the land use/land cover (LULC) of a city, especially in the peri-urban areas which occurs due to the evolving societal priorities emphasising more on built-up segment (Maiti and Agrawal 2005). Pull migration creates immense pressure on urban land and housing, and the availability of green space becomes scarcer for the urbanites (Ministry of Environment and Forest 2010). But in case of such rapid urbanisation, urban forestry, through mixed plantations, needs to play a vital role in the urban renewal programmes. Importance of urban vegetation and forest has been harped by many, but most of the forest managers do not have much idea about appropriate species selection, care and maintenance (Chacalo et al. 1994) and even lack the information about the streets to formulate holistic urban forestry plan (Jim and Chen 2008). Chaudhry et al. (2011) compared the urban forest scenario of Indian cities with that of the counterparts in Europe and America and highlighted the need of increased urban greenery in the Indian cities to bridge the gap. The authors suggested to follow the Chinese model where similar high population density has been negotiated while enhancing the urban greenery through formation of over hundred 'National Garden Cities' along with that of Singapore.

6.2 Previous Works

Konijnendijk (2008) noted that the idea of urban forestry was germinated long back in 1894. The most inclusive definition of urban forestry was provided by Grey & Deneke (1986) who defined that urban forestry is all about tree management involving woodlands, tree groups – parks and greenbelts, standalone trees along the streets and utility corridors, in the urban fringes and in every nook and corner of the city be it public or private land which ultimately contributes positively to the ecological, physiological and economic well-being of urban society. To make the concrete jungles habitable in the long run, the concept of urban forest seemed befitting for the developed countries. The trend was followed in the developing world too as urbanisation wave hit them; the potential of urban forest in generating livelihood options was also harnessed (Carter 1995). There is a contentious issue regarding the jurisdiction on which urban forestry is developed, i.e. the government initiated and community/private owned (Brendler and Carey 1998). Urban forestry was first theorised in North America during late 1960s (Miller 1988). Konijnendijk (2000) pointed out a very important distinction between classic and urban forestry – urban forestry has come up as a response to specific demands (social, environmental, aesthetic) of the local urban community, while traditional forestry is more focussed on the economic value generated through the timber and non-timber forest produces. In recent times there have been reinvigorated efforts by the government to create urban forestscape for ecological benefits leading to the development of 'eco-cities' (Hall 2002). leading to development of 'eco-cities'. to more accessible public-space greenery can be documented (Konijnendijk 2008) which has made urban parks representatives of 'social forest' where community and vegetation interact directly. Gerhold penned down the all-inclusive definition of urban forestry which highlights the importance and utilities of greenscape in urban societies. Urban forestry thus embraces the supervision of individual as well as groups of trees, and arboriculture is an important section of urban forestry (Krishnan 2007).

Urban trees provide both tangible and intangible benefits to the city dwellers (Table 6.1). Tangible benefits include food, fodder, fuel wood, etc. and parks, shades and shelter are the intangible benefits enjoyed by the city residents. As various scientific studies on urban green space stressed on the manifold benefits of green areas (Lyytimäki and Sipilä 2009), worldwide, there have been consorted efforts to set up parks and squares under the aegis of International Federation of Parks and Recreation Administration, World Urban Parks Initiative. Green infrastructure is indispensable for enhanced quality of urban life. The services rendered by urban forests are myriad – helps in pollution reduction, noise abatement, improvising micro-climate, providing local recreation, increasing real estate values, etc. (Jones et al. 2008). In 2006, the Food and Agricultural Organisation (FAO) threw light on how urban greens generate economic activities around them like amusement park-related small businesses, and another interesting aspect which also surfaced is that of food security involving urban forests and urban agriculture (Basu and Kar 2021). Preservation or creation of green spaces is important in urban areas for leisure or

Table 6.1 Manifold benefits reaped from urban greenery

Parameters	Beneficial aspects
Ecological	Acts as source of oxygen, absorbs pollutants improving air quality (Brack 2002; Nowak et al. 2006)
	Plays important role in carbon sequestration through carbon storing (McPherson and Simpson 1999)
	Helps in lowering temperature, reducing urban heat island impact (Gill et al. 2007)
	Improves micro-urban climate in general (Vailshery et al. 2013)
	Preserves limited urban biodiversity (Attwell 2000)
	Reduces surface water runoff, flood control (Armson et al. 2013)
	Mitigates effects of climate change (Munang et al. 2013)
	Controls the noise impact in urban regions (Fang and Ling 2003)
Social	Provides refreshing contrast in the monotonous urban landscape creating aesthetic appeal (Attwell 2000)
	Acts as space for social interaction for people of different age groups like youngsters and elderlies (Konijnendijk et al. 2013)
	Encourages persuasion of cultural life through local festivals, fairs leading to social cohesion and boosting of local economy (Konijnendijk 2000)
	Helps refresh the health and minds of the urban dwellers through creation of recreation spaces reducing stress and anxiety and helping in general wellbeing (Maas et al. 2006)
Economic	Plays a vital role in alleviating poverty, advancing livelihoods and improving wellbeing for the marginalised poor people in developing countries by offering environmental services like grazing and fuelwood collection (Kuchelmeister and Braatz 2001).
	Helps in creating pricier residential units with neighbourhood parks where posh urban dwellers are eager to pay a fortune to live within or nearby urban greenery (Grinspan et al. 2020)
	Aids in reducing building air-conditioning load by keeping the surroundings cool through shady trees (Simpson 1998)
	Boosts the local economy with increased paid leisure visits to the parks generating urban leisure and tourism (Konijnendijk et al. 2013)
	Provides shelter to the roadside vendors under the shady trees (Bhattacharya and Nigam 2010)

Source: Compiled by authors, 2021

recreation purposes; it is also essential to maintain the biodiversity chain (Zaman et al. 2014). However, creating only isolated green pockets is not the actual purpose; to make the crowed cities truly sustainable, the UGS need to be systematically integrated with the urban landscape.

To maintain a minimum level of urban green spaces (UGS), there are several recommendations regarding standardised quantum of green space (20–40% of total area); most of the developed countries have adopted a policy of having 20 sq.km of green space per capita, while the World Health Organization (WHO) prescribed 9 sq. m of open green space for each inhabitant, so that all residents can have access to an open space within a walking distance of 15 min (Town and Country Planning

Table 6.2 Estimates of urban green spaces in selected cities of India

City	Per capita green space (sq.m/inhabitant)
Gandhinagar	162.80
Varanasi	24.78
Nagpur	31.00
Allahabad	24.06
New Delhi	21.43
Chandigarh	54.45
Noida	16.49
Ahmedabad	3.90
Kanpur	3.76
Bengaluru	17.79
Amritsar	0.95
Chennai	1.03
Trivandrum	0.55
Jaipur	2.30
Hyderabad	0.50
Vishakhapatnam	0.18
Mumbai	2.01

Data Source: Govindarajulu 2014; Town and Country Planning Organisation 2014; Chaudhry 2016; and Imam and Banerjee 2016

Organisation 2014). Leadership in Energy and Environment Design Neighbourhood Development (LEED ND) went a step ahead to recommend a green cover of >20 sq. m per capita or to maintain a minimum of 1.25 ha of open space per 1000 residents to ensure that within a distance of 200 m of residential area, there is some sort of urban green space (Govindarajulu 2014). Konijnendijk (2001) carried out a survey on 26 large European cities which had an average 18.5% green coverage with per capita being around 104 sq.m. In case of Paris, France and Canberra, Australia Moigneu (2001) and Brack (2006) noted that per capita green space was around 80 sq.m. But for unprecedented urban growth with very high population density, it becomes difficult for the Indian cities to maintain a high urban green space percentage barring few to maintain the WHO prescribed norm (Table 6.2).

Few worth mentioning studies are on Bangalore (Nagendra and Gopal 2010), Chandigarh (Chaudhry and Tewari 2011) and Delhi (Khera et al. 2009). A comparative study by Chaudhry (2016) shows that Gandhinagar in Gujrat state has the maximum per capita green space.

At a regional scale, West Bengal too is facing the problem of rapid urbanisation and population rise. The urban population of the state rose from 27.8% in 2001 to 31.8% in 2011 (Census of India 2011a). This kind of urban population explosion has led to emergence of about 35 million-plus cities (Ministry of Housing and Urban Affairs 2011), several smaller cities and towns causing widespread depletion of green cover impacting biodiversity and climate in the long run. Foreseeing the rapid rise in urban population, the government published the township policy emphasising sustainable, eco-friendly, resilient and affordable housing. Kolkata, like any other speedily growing metropolis in the country, is facing critical glitches of rapid urbanisation and, therefore, needs the enactment of a strategic regional planning (Kolkata Metropolitan Development Authority 2005). Mukherjee et al. (2018) while dealing with urban water scarcity scenario in Kolkata, highlighted the changing LULC of the city and emphasised on the uncontrolled urbanisation leading to decreasing green cover too. Apart from expansion of cities, other factors that contributed to the shrinking of green space are increasing population, reduction in residential gardens and kitchen gardens giving way to skyscrapers. This leads to concretized surroundings which ultimately snatches away the wee bit of urban green cover (Gangopadhyay and Balooni 2012). In case of Kolkata, the per capita green space is not readily available, but as per a World Bank study of 2011, the city had only 9.5% in the form of parks and open spaces. As per municipal records, there are 711 parks in total of varying sizes in the city. As per the study conducted by a research group from the Indian Institute of Science based on satellite imageries, it was derived that Kolkata including a 10 km buffer zone surrounding the city had a sharp declining tree cover from 33.6% in 1980 to 7.36% in 2010 and was predicted to become as low as 3.37% in 2030 (Padmanabhan 2016). Ramachandra et al. (2014) carried out a temporal LULC on Kolkata while modelling the urban structure and exposed a decline of vegetation from 33.6% in 1980 to 7.36% in 2010.

Mandal et al. (2019) studied the spatio-temporal land use/land cover changes (1991–2018) in the megacity of Kolkata and predicted the future urban growth trajectory. They emphasised the negative relationship between urbanisation and vegetation cover and expressed concern over further decreasing green cover as derived from prediction through CA-Markov chain model. Kundu et al. (2020) focused on urban change detection analysis at Kolkata (1978–2017) through usage of multi-temporal satellite data highlighting that at the expense of urban built-up area, other land use categories including vegetation suffered a setback. Rahman et al., 2019 Sahana et al., 2018 and Sahana et al., 2019 has assessed the landscape fragmentation and its relation with the urban green space in Kolkata Urban agglomeration. Mallick et al., 2021 explore the impact of future urban growth and its impact on the urban green space for a small city near Kolkata. The impact of roadside vegetation on air pollution in the megacity of Kolkata has been studied by Karmakar et al. (2021) and showed that increasing vehicular pollution had reciprocal correlation with species richness and species diversity highlighting the few selected tolerant species. Dinda et al. (2021) adopted an integrated simulation approach to predict the LULC dynamics of 2025 and 2035 and prior to that examined the loss in urban green space in Kolkata (1980–2018). The study projected a loss in urban vegetation of about (−)17.42% and (−)11.69% for the period of 2025–2035, respectively.

6.3 Rationale of the Study

From the above discussion, it is clear that there has been extensive research about UGS at global and national scale along with a handful studies on megacity of Kolkata identifying the gradual shrinkage of urban greenery. There have been a number of studies on the changing LULC and shrinking UGS of the city, but the novelty of the present study is that it is not limited to the use of geospatial techniques to inspect spatio-temporal LULC changes and declining vegetation health. The study attempts to address few lesser discussed aspects like calculation of person-park ratio, preparation of tree inventory and investigation of loopholes in arboricultural practices within the city limits. Besides, identification of suitable zones for peri-urban forest development and perception studies of urban dwellers about the diverse role of urban forestry adds to the holistic overview.

6.4 Study Area

Kolkata (formerly Calcutta), the city with rich colonial heritage, is tenth-largest urban agglomeration of the world, the largest metropolitan city of eastern India and the second highest populated one in the entire country. The study area encompasses the Kolkata Municipal Corporation (KMC), located at the eastern bank of the Hooghly river along with the satellite urban entities like Bidhannagar municipality and New Town, Rajarhat, situated in the lower deltaic plains of the Ganga-Bhagirthi-Hooghly river system. The region experiences tropical wet and dry climate [Aw as per Köppen's climatic classification system] (Maplecroft 2016).

KMC having an approximate area of 206.08 sq.km comprising of 144 wards (141 wards till August, 2016) grouped into 16 boroughs (previously 15), i.e. administrative units, is a part of the greater identity Kolkata Metropolitan Area having an area of 1887 sq.km (Fig. 6.1). It is one of the densest cities of the world with population density of 24,306 per sq.km (Census of India 2011b). With the increasing urbanisation, there has been overcrowding within city of joy and causing change in LULC and continuous environmental degradation. Keeping in mind the IUCN Aichi Biodiversity Targets, Paul and Bardhan (2017) felt that it was high time to benchmark the urban biodiversity of the city of Kolkata and carried out an index-based survey which revealed Kolkata being a 'Brown city in Green Background' having rich native biodiversity but facing random deforestation alongside introduction of exotic species due to high urban sprawl. This necessitates the need for a comprehensive urban land use planning giving due importance to create and sustain urban greenery.

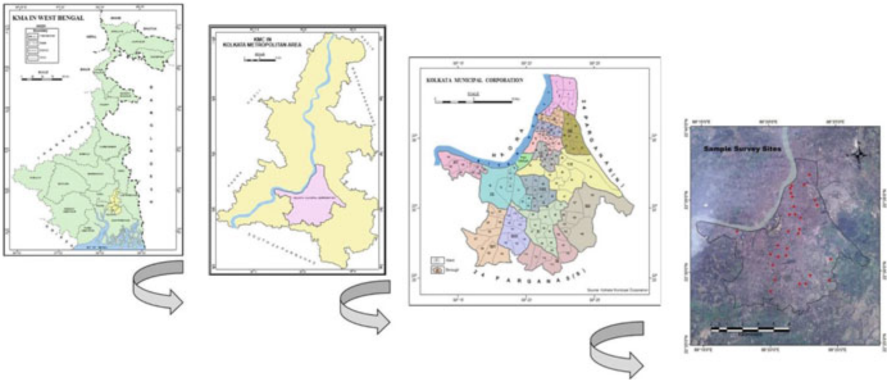

Fig. 6.1 Introducing the study area – Kolkata Municipal Corporation with ward boundary and sample survey sites

Table 6.3 Details of satellite imageries taken into account

Satellite type	Sensor ID	Path/row	Date of capture	Spatial resolution (m)
Landsat_8	OLI_TRS	138/44	15/11/2020	30
Landsat_7	ETM (+)	138/44	17/11/2000	30
Landsat_3	MSS	148/44–45	14/11/1980	80

Source: USGS, 2020

6.5 Database and Methodology

This paper is based on secondary data collected from different literature sources, reports, etc. as well as on intensive field based primary observations. Both qualitative and quantitative data have been used for the analysis. Satellite images of over a period of time (1990, 2010 and 2020) have been collected for determining the evolving scenario of urban greenery in the study area. Three cloud free Landsat images of the month of November are selected and downloaded from the US Geological Survey (USGS) website for further processing (Table 6.3).

For the digital image processing of the satellite imagery, ArcGIS v10.3 has been used. To minimise the different errors of standard images from varied sensors, noise from different sources and lens distortions, etc., geometric and radiometric corrections were done, and in this case, after necessary atmospheric corrections and instrumental error removals, image enhancement techniques like histogram equalisation and contrast enhancement were carried out. Besides, the images were co-registered to match the overlay with sub-pixel accuracy; then for resampling, nearest neighbourhood technique were applied. The transformation error recorded was 0.45 pixel in all instances. On the basis of Survey of India, topographical sheets of 1:50,000 and municipal ward map of Kolkata Municipal Corporation, the study area was delineated, and a vector layer of the KMC region was used for clipping and subsetting.

Table 6.4 Land use and land cover changes in Kolkata Municipal Area, West Bengal, India (1980 to 2020). Spatio-temporal land use/land cover statistics LST

Land use and land cover	1980		2000		2020	
	Sq.km.	%	Sq.km.	%	Sq.km.	%
Built-up	91.63	49	132.77	71	151.47	81
Water bodies	14.96	8	9.35	5	7.48	4
Vegetation	57.97	31	37.4	20	20.57	11
Open field and others	13.09	7	5.61	3	5.61	3
Bare land	9.35	5	1.87	1	1.87	1

Source: Computed by authors from satellite imageries of Landsat 3, Landsat 5 and Landsat 8 for 1980, 2000 and 2020, respectively

Then supervised classification of the desired area from the pre-processed images was done with the help of maximum likelihood algorithm on the basis of training sets (signature) assigned by the user on the basis of reflectance characteristics and corresponding ground truth verification.

The training data given by the user guides the software as to what types of pixels are to be selected for certain land cover type. The classification yielded the land use/land cover image of the area with five main classes, namely, built-up, water bodies, vegetation, open field and others and bare land (Table 6.4).

Table 6.4: Land use and land cover (LULC) classification schemes

Class name	Description
Built up	Residential areas, functional areas, utilities zones, industrial, roadways, railways, other built-up or urban land
Water bodies	Rivers, canals, lakes, ponds, reservoirs and wetlands
Vegetation	Mixed trees, scrublands, grasslands, urban agriculture
Open field and others	Permanent fallow land, unused land, landfill sites
Bare land	Barren land

Source: Classified by authors from satellite imageries of Landsat 3, Landsat 5 and Landsat 8 for 1980

Accuracy assessment has been done to ensure the performance quality of the classifiers. To assess the accuracy level of the classification, ground truth verification has been done with the help of handheld GNSS device (Garmin GPS Etrex-30) with a positional accuracy of 3 m through field surveys held in two phases and high-resolution Google Earth imagery of similar corresponding periods from Google Earth Pro. By using the random sampling method, a total of 200 points are selected from different LULC classes with a minimum 40 points from each class for each year, and then it is reviewed with Google images. Kappa coefficient (k) [$k = (P_O - P_e)/(1 - P_e)$] is used to measure inter- and intra-reliability for categorical entities (Cohen 1960), where the score varies from 0 to 1; the higher the value, the greater is the degree of agreement. Error matrix is computed to reflect the overall accuracy and the Kappa coefficient value for each year concerned.

To have an idea about the health of the urban greens, Normalized Difference Vegetation Index (NDVI) has been used, which has proved to be an efficient technique in vegetation change detection and derivation of canopy biophysical characteristics of a particular region. The NDVI is calculated as a ratio between measured reflectivity in the red and near-infrared portions of the electromagnetic spectrum. The NDVI transformation is computed as the ratio of the measured intensities in the red and near-infrared (NIR) spectral bands (ones most affected by the absorption of chlorophyll by the green plants).

$$\left(\mathrm{NDVI} = \frac{\mathrm{NIR} - \mathrm{Red}}{\mathrm{NIR} + \mathrm{Red}}\right)$$

The value of NDVI ranges from 0 to 1. A value closer to 1 represents healthy vegetation, and a value closer to 0 represents unhealthy vegetation.

The Enhanced Vegetation Index (EVI) is an advanced vegetation index created with higher sensitivity to biomass, atmospheric background and soil condition. It is contemplated as the modified version of NDVI with high potentiality of vegetation monitoring by correcting all the external noises. Vegetation indices are calculated from the bilateral surface reflectance that has been concealed for cloud, smoke, aerosols, water, cloud shadows, etc. EVI uses the blue and red NIR band (band 1, 3 and 4 for Landsat 5 TM and band 2, 4 and 5 for Landsat 8 OLI) with the correction coefficient C1, C2 and L (Gao and Li 2000). In recent times, EVI has proved to be an efficient technique in vegetation change detection and derivation of canopy biophysical characteristics of a particular region, so it has been applied in the study area for vegetation analysis.

Besides, intensive field survey in two phases (January–March 2020 and August–October 2020) was carried out to cover the entire city at length keeping the season and COVID-related movement restrictions in mind to classify urban greens and prepare a detailed inventory of the urban greens of the city along the major thoroughfares and locate the few major pockets of urban greens and forests within the city limits. During the surveys, identification of common loopholes in arboriculture practices was noted too. To access how the citizens of Kolkata are involved with urban greenery amidst their busy daily schedules and through dendrogram, key factors for generating people's perception on urban greenery have been analysed. To understand the people's perception regarding urban forestry and its management practices, online questionnaire survey was conducted on randomly selected residents ($n = 1410$).

6.6 Results

6.6.1 *Spatio-temporal Change Analysis*

The supervised classification has been applied to detect the LULC changes within KMC area (Fig. 6.2). It can be identified that the spatial pattern of the city shows major changes in built-up area, vegetation cover and water bodies along with open spaces and bare land.

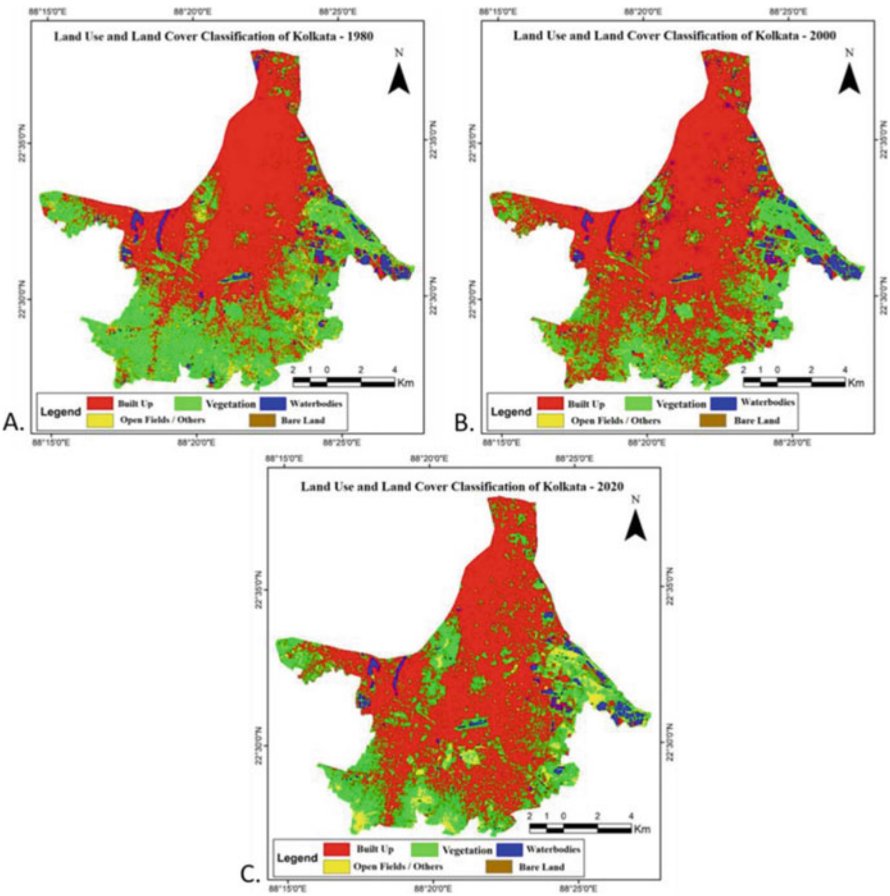

Fig. 6.2 Gradual transformation in land use and land cover of Kolkata, West Bengal. The LULC maps (1A, 1B, 1C) with the help of satellite imageries of Landsat 3, 5 and 8 for 1980, 2000 and 2020, respectively, show the extent of growing urbanisation and diminishing vegetation in the region

The land use classes have been mapped covering the period of 1980, 2000 and 2020. Distinct changes can be observed in the major LULC classes (Table 6.4). In 1980, the built-up area covered 49% (91.63 sq.km.) of the total KMC area, while in 2020, it almost engulfed the whole KMC area covering 81% (151.47 sq.km.) of the total area. The rate of urbanisation was much rapid during the phase 1980–2000 (22% increase in built-up) than that of the time frame 2000–2020 (10% increase in built-up). This has resulted in decrease in the vegetation patches throughout the city.

The vegetation cover includes roadside trees, green fields and other green patches. During the 1980s, the vegetation of the city comprised mainly of big trees which covered an area of 31% (57.97 sq.km.) of the total KMC area. In the year 2000, the green cover drastically shrank to 20% (37.40 sq.km.) of the total KMC

Table 6.5 Error matrix for land use and land cover changes in Kolkata Municipal Area, West Bengal, India (1980–2020)

Year	Class name	Reference total	Classified total	Number of correct points	Producer's accuracy	User's accuracy	Kappa statistics
1980	Built-up	46	42	38	82.61	90.48	0.88
	Water body	30	24	20	66.67	83.33	0.80
	Vegetation	54	58	40	84.21	64.00	0.56
	Open fields and others	28	34	26	92.86	76.47	0.67
	Bare land	42	40	34	88.24	78.95	0.68
	Total	***200***	***200***	***158***	***79.00***		***0.72***
2000	Built-up	48	54	46	95.83	85.19	0.81
	Water body	32	34	32	100.00	94.12	0.93
	Vegetation	52	44	34	68.18	75.00	0.67
	Open fields and others	30	34	20	52.63	83.33	0.93
	Bare land	38	34	32	76.47	76.47	0.64
	Total	***200***	***200***	***164***	***82.00***		***0.76***
2020	Built-up	96	104	98	100	94.23	0.88
	Water body	28	35	28	100.00	77.78	0.74
	Vegetation	46	26	22	52.63	83.33	0.79
	Open fields and others	13	7	6	84.21	64.00	0.82
	Bare land	17	28	20	92.86	76.47	0.72
	Total	***200***	***200***	***174***	***87.00***		***0.81***

Computed by the authors from satellite imageries of Landsat 3, Landsat 5 and Landsat 8 for 1980, 2000 and 2020, respectively

area and ultimately to 11% (20.57 sq.km). It is interesting to note that vegetation patches showed a slight increase in the eastern part of the city along with the southern fringes where scattered vegetation pockets could be located. Sharp decline in vegetation and consequent increase in built-up can be seen in the boroughs X, XI and XII between 1980 and 2020. The changes for the vegetation patches were major in the boroughs of II, VI and V.

For accuracy assessment of the classification, user's accuracy and producer's accuracy for each land cover types have been conducted along with kappa statistics for each land cover types (Table 6.5). The kappa statistics has been used to verify the inter-rater reliability. The higher observer accuracy highlights the overall agreement level. In general, the overall accuracy of the imagery interpretation ranges from 72% to 81%.

With the growing urbanisation process, the green cover in Kolkata has shown a declining trend. Rapid population growth leading to rigorous urbanisation has led to the clearance of a fair share of the green areas of the city. The population growth mostly due to pull-factor-based migration and the resultant hanging nature of the LULC within KMC area cause a sharp decline in the urban greenery in the city which is gradually becoming a ‘concrete jungle’ acting home for more than 4.5 million residents.

6.6.2 Urban Green Space Analysis

In this study attempt has been made to identify the urban green spaces which are at high risk due to rapid growth of urbanisation. The risk vulnerability of the urban greenery has been highlighted using NDVI values categorised as low, high and very high (Fig. 6.3). The values ranging within 0.2–0.4 indicate sparse vegetation cover.

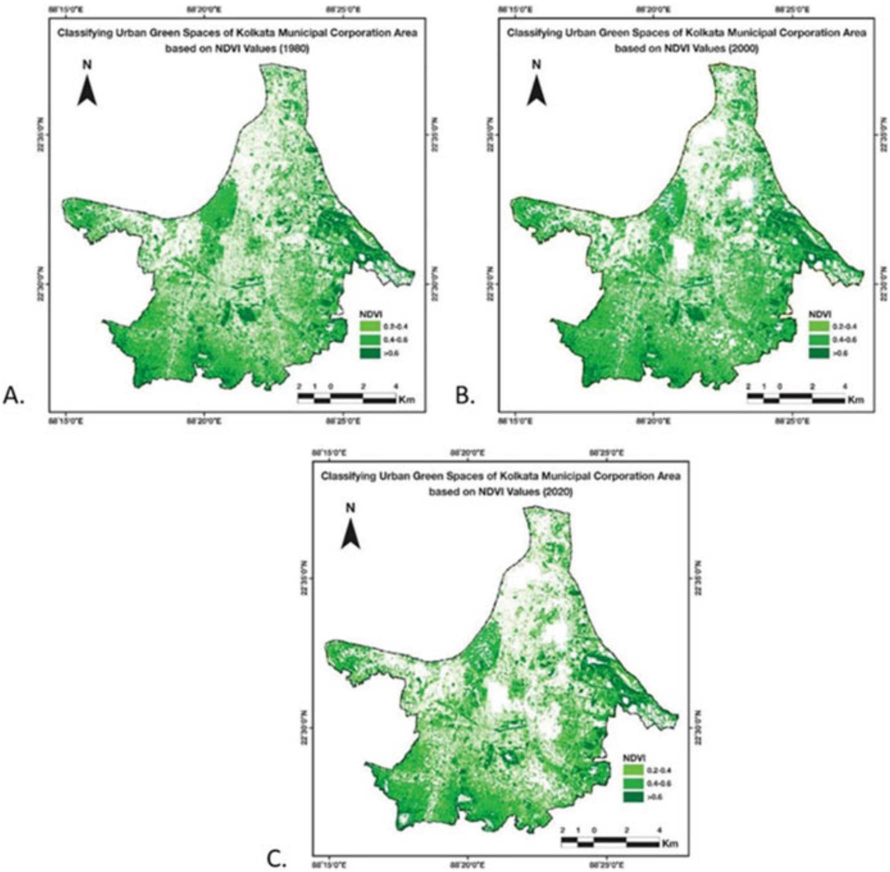

Fig. 6.3 Classifying urban green spaces based on NDVI values (1980–2020), Kolkata, West Bengal, with the help of satellite imageries of Landsat 3, 5 and 8 for 1980, 2000 and 2020, respectively

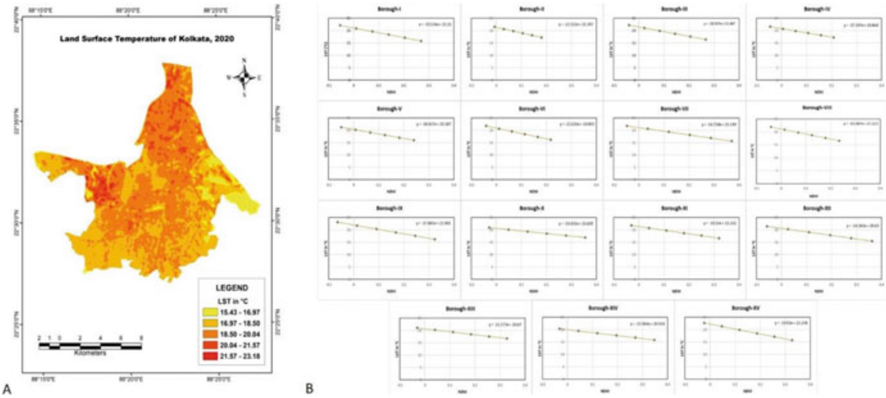

Fig. 6.4 Borough-wise graphs showing negative co-relation between NDVI and LST (2020)

It is well established that since 1980, the vegetation cover has shown a decline. The zones having value above 0.6 are the areas that are stable and are expected to survive the stress of the rapid urbanisation.

Land surface temperature (LST) refers to the 'skin' temperature of the surface, which depends on insolation alongside the nature of the surface. It indicates the terrestrial thermal behaviour; normally vegetated areas, water bodies are cooler in comparison with sand or concretised surfaces. So, a positive relation exists between LST and urbanisation. In case of Kolkata too, the LST (of 2020) approximately varies from 15 °C to 23 °C; the lower temperatures are located where presence of vegetation is higher, i.e. predominantly in the southern and eastern parts (Fig. 6.4).

The growing population and extreme exploitation and utilisation of natural resources result in a severe change in land use and land cover pattern in the urban areas. The connection between the land use and land cover pattern and the different materials like bricks, asphalt, concrete, etc. used in urban areas has become necessity to understand its impact on the environment (Stone and Rdgebers 2001). All these materials have high thermal inertia, greater absorption of solar radiation and high thermal conductivity (Arrau and Peña 2010). The evaporation regime gets altered due to the conversion of vegetated areas into concrete surfaces. The lowest LST values are found in areas with high NDVI. The regression analysis of LST and NDVI shows a linear negative correlation which becomes an important parameter for studying urban climate. For all the 15 boroughs, the relationship is negative to strongly negative where correlation coefficient ranges between −0.89 and − 1. North Kolkata and parts of central and western Kolkata show a strong negative correlation. This indicates that areas with least vegetation are experiencing higher land surface temperature.

Constant monitoring of vegetation is necessary to get an overview about the strength and dynamics of canopy structure which may indicate the change due to developmental activities and climate change. EVI similar to NDVI corrects the noises – background, atmospheric noise and saturation – and can be used to quantify vegetation greenness. EVI is similar to Normalized Difference Vegetation Index

(NDVI) and can be used to quantify vegetation greenness. The Enhanced Vegetation Index (EVI) has been done to augment the vegetation signal with a better sensitivity in the areas of green cover. The improved green monitoring is possible by separating the canopy background signal and reducing the atmospheric influences. It incorporates an 'L' value to adjust for canopy background, 'C' values as coefficients for atmospheric resistance and values from the blue band (B). These enhancements allow for index calculation as a ratio between the R and NIR values while reducing the background noise, atmospheric noise and saturation in most cases (USGS 2019). EVI has been calculated using below formula:

$$\mathrm{EVI} = G \times \left\{ \frac{(\mathrm{NIR} - \mathrm{Red})}{(\mathrm{NIR} + C1) \times (R - C2 * B + L)} \right\}$$

The green cover for the three selected years 1980, 2000 and 2020 has been shown in Fig. 6.5. The increasing urbanisation is the most important factor that has led to the continuous decrease in the green cover in the urban area like Kolkata. The 2020 EVI map clearly shows the decrease in the green cover in Kolkata compared to 1980.

The city is dotted with many parks of varying sizes (small, medium and large) though there is a kind of underlying inequality in distribution. Based on the municipal records, it was calculated that the average value of number of persons served by a single park was as high as 9081. Borough X, followed by boroughs of XI and XIII all in south Kolkata, provides the least value of persons served by a single park – having a value ranging between 3000 and 4000. North Kolkata (boroughs IV, V and VII) has lesser scope for urban greens as the degree of urbanisation is very high providing higher person-park ratio. Borough XV shows an exceptionally skewed ratio of 30,891 as not much effort has been taken in developing formal urban green spaces (Fig. 6.6).

Li et al. (2005) developed an integrated ecological network for green, sustainable development of Beijing, China; Uy and Nakagoshi (2007) created a framework for urban green space development in Hanoi City, Vietnam; and Kong et al. (2010) developed green space network for Jinan City, China. Scholars like Teng et al. (2011) emphasised on integrated green space planning involving recreation and conservation side by side. This sort of approach is needed for Kolkata too to do away with the gross areal disparities and ensure somewhat equal access to greenery for all its citizens.

6.6.3 Preparation of Tree Inventory

Apart from the planned green spaces, avenue and median plantations also play an important role in maintaining the green cover of the city. But taking a close look at the prominent species involved will help in understanding the treescape (Table 6.6). Intensive field survey in two phases (January–March, 2020 and August–October, 2020) was carried out across the city, and on the basis of their canopy structure, characteristics and predominant locational presence, classification has been done (Fig. 6.6).

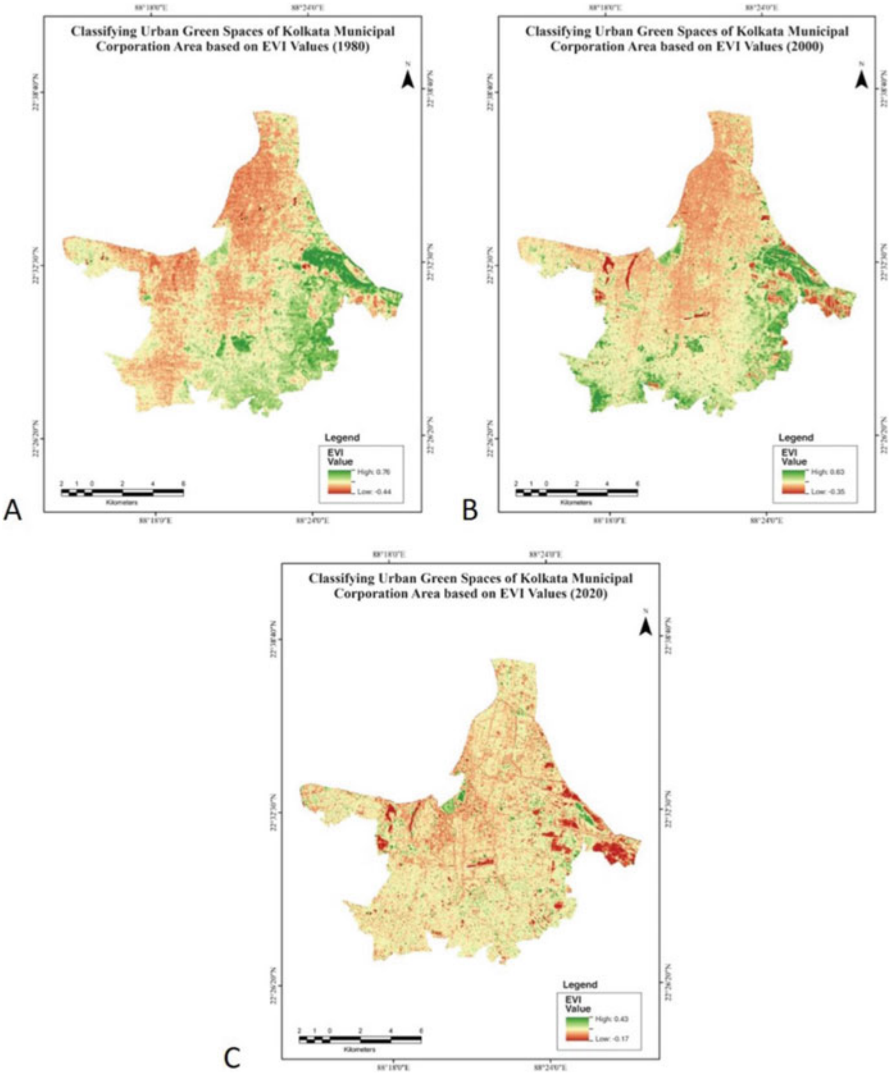

Fig. 6.5 Classifying urban green spaces based on EVI values (1980–2020), Kolkata, West Bengal, with the help of satellite imageries of Landsat 3, 5 and 8 for 1980, 2000 and 2020, respectively.

In a city like Kolkata where automobile pollution and dust smoke are highly prevalent, certain species are highly suitable and are commonly seen like Sirish/rain tree (*Samanea saman*), white Sirish (*Albizia procera*), Indian Sirish (*Albizzia lebbek*), Bael/wood apple (*Aegle marmelos*), Palash/flame of the forest (*Butea monosperma*), Bakul/Spanish cherry (*Mimusops elengi*), etc. However, an attempted detailed inventory would help in having a clearer overview (Fig. 6.7).

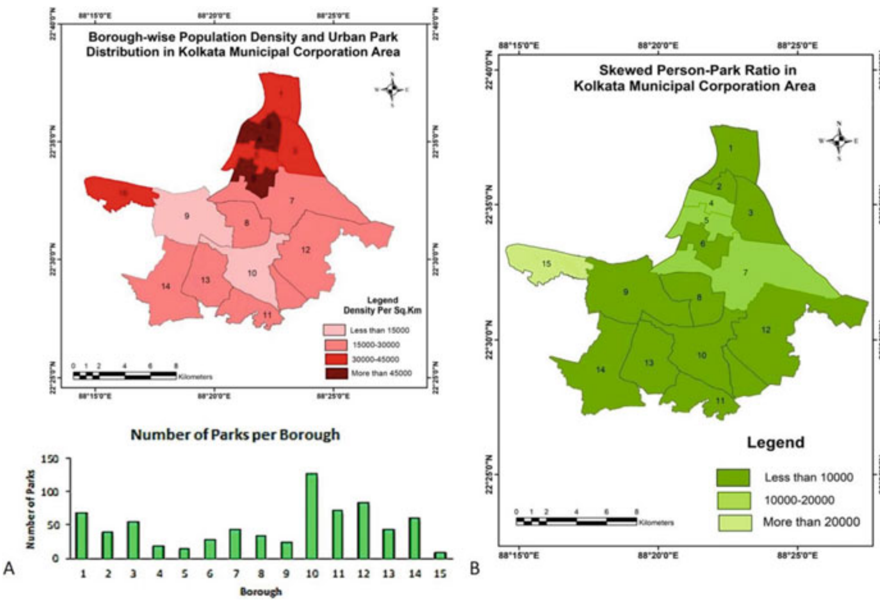

Fig. 6.6 A. Borough-wise population density of Kolkata Municipal Corporation Area with corresponding park distribution; B. skewed park presence and high population density leading to unsatisfactory person-park ratio in Kolkata Municipal Corporation Area. Data Source: Kolkata Municipal Corporation 2020

6.6.4 People’s Perception on Urban Greenery

UGS assists in various primary functions mostly preservation and nourishment of natural processes like the biogeochemical cycles, sustenance of flora and fauna and upkeeping of mental health through remodelling and enhancement of the appearance of any area. Theoretically, among the academicians, there is a consensus that increased citizen involvement in urban forestry initiatives will increase its efficacy. To facilitate such involvement for the state of Pennsylvania, Thompson et al. (2005) recommended techniques like stakeholder mapping, key informant interview and snowball sampling. To further investigate the matter of citizens' concern for urban greenery and the resultant municipal eagerness to involve locals in urban forestry initiatives of various municipalities have been studied. Scholars like Reeder and Gerhold (1993), Ricard (1994) and Kuhns et al. (2005) tried to gauge about the perception of both the stakeholders and mostly highlighted a gap indicating lesser empowered role of the citizens in terms of decision-making involving wise-practices, management, budgetary allocation, etc. In case of Indian cities, such studies are conspicuous by their absence.

The dendrogram represents the relationship of similarity among the response collected from the primary survey (Fig. 6.8). The diagram has four clades with seven leaves. The height of the dendrogram indicates the order in which the clusters were

Table 6.6 Treescape of Kolkata City, West Bengal, India

Trees with roundish crown		
Scientific name	**Common name**	**Location**
Mimusops elengi	Bakul	Avenue plantation
Azadirachta indica	Neem	Avenue plantation and private garden
Neolamarckia cadamba	Kadamba/burflower	Avenue plantation
Ficus religiosa	Peepal/Bodhi	Avenue plantation, exceptionally beneficial for carbon storage
Swietenia mahagoni	Spanish mahogany	Avenue plantation
Terminalia arjuna	Arjun	Avenue plantation
Mangifera indica	Mango	Avenue plantation and private garden
Trees with umbrella-like crown		
Scientific name	**Common name**	**Location**
Ficus benghalensis	Banyan	Parks
Lagerstroemia speciosa	Banaba/Pride of India	Median plantation with ornamental flowers
Thespesia populnea	Indian tulip tree	Avenue plantation
Delonix regia	Gulmohar/flame tree	Though popular as avenue plantation is highly susceptible to strong winds and thus more suitable for parks and private garden providing vibrancy
Alstonia scholaris	Saptaparni/Devil's tree	Though popular as avenue plantation is highly susceptible to strong winds and thus more suitable for parks and private garden
Sterculia foetida	Wild almond tree	Scattered avenue plantation
Samanea saman	Rain tree	Avenue plantation
Tamarindus indica	Tamarind	Avenue plantation
Averrhoa carambola	Kamranga/starfruit	Median plantation
Eugenia operculata	Jamun	Avenue plantation
Trees with columnar crown		
Scientific name	**Common name**	**Location**
Putranjiva roxburghii	Putranjiba/lucky bean tree	Avenue plantation

(continued)

Table 6.6 (continued)

Spathodea campanulata	African tulip tree	Ornamental purpose
Peltophorum pterocarpum	Copper pod	Avenue plantation though susceptible to strong winds
Terminalia catappa	Indian almond tree	Avenue plantation though susceptible to strong winds
Bombax ceiba	Simul/silk cotton	Parks
Swietenia macrophylla	Honduras mahogany	Parks
Alstonia scholaris	Saptaparni/Chhatim/ Blackboard tree	Avenue plantation
Ficus religiosa	Peepul/sacred fig	Avenue plantation
Diverse flowering trees		
Scientific name	**Common name**	**Location**
Cassia fistula	Amaltas/golden shower	Brightening avenue scenario
Bauhinia purpurea	Kanchan/purple orchard	
Colvillea racemosa	Kilbili/Colville's glory	
Peltophorum ferrugineum	Swarnachura/yel-low flame	
Spathodea nilotica	Rudrapalash/foun-tain tree	
Jacaranda acutifolia	Nilkantha/blue Jacaranda	
Grevillea robusta	Rupashi/silver oak	

Source: Primary Survey (2020) and Sarkar (2016)

joined. The arrangement of the clades highlights the similarity among the leaves. The greater the height of the branch, the greater is the difference. In this dendrogram, seven basic questions were enquired regarding the surrounding green space, and thus seven chunks were derived. In this diagram chunk, one which represents the distance of park from home has been separated and is categorised as simplicifolious. The separation of this category from the others indicates that most respondents were of opinion that the green spaces are always not at walkable distance. As the distance of the first parameter increases, it denotes a common general view of the respondents that most parks are located at a distance that is often difficult to travel. The second clade shows a separate branching highlighting people's acceptance of aesthetic values of the greenery. With people admitting to the need for the green space, the recurring constructional works and growing urbanisation have made it difficult to maintain the greenery. The third clade has three branching with a separated branching highlighting the green space like parks for pets. Shading and privacy

Fig. 6.7 Glimpses of greenery from across the city: A. Subhas Sarovar; B. Park Circus Maidan; C. Southern Avenue; D. Maddox Square; E. Maidan; F. Elliot Park; G. KMC Park, Behala; H. Sarat Bose Road; I. Javadpur Yuba Sangha Ground

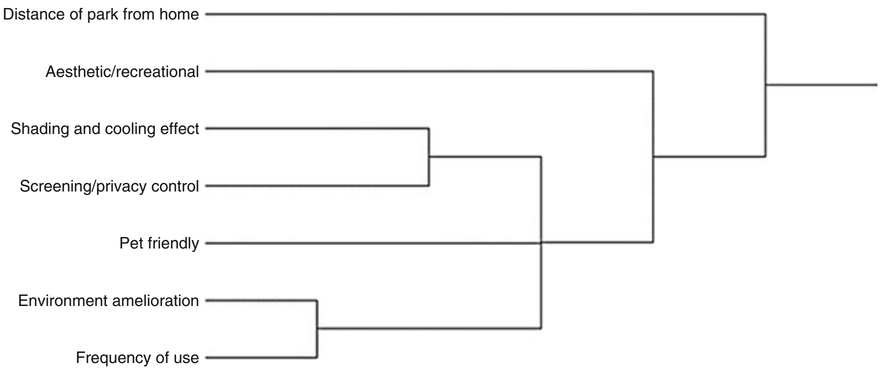

Fig. 6.8 Analysing the key factors for generating people's perception on urban greenery. Source: Primary Survey, 2020

issues show similarity indicating a dissimilarity with the first two parameters. People are, however, less acquainted with environmental amelioration. Frequency of use is often affected by the distance of the parks from the residences. This distance has shown a separate branching indicating the most vital criteria for usage of green space.

Through contingent valuation method (CVM), the annual recreational usage value of UGS of Chandigarh was estimated to be around 120 million rupees taking 2002–2003 as the base year, and Willingness to Pay method indicated that maintenance cost of the existing greenery per family per year agreed to pay little over

150 rupees (Chaudhry 2006). In Kolkata also, it can be very well gauged that urban greenspace can provide the least requirements of natural setting to avoid psychological isolation of people from their immediate environment. The respondents have opined that establishment of new parks, roadside plantation and adoption of mass tree plantation programmes can be beneficial for developing urban greens. There has been a positive attitude toward environmental development, its management and protection. The optimal carrying capacity of the urban greens and recreational areas can be improved if more trees are planted alongside the maintenance of the greenspaces.

6.7 Discussion

6.7.1 Classifying Urban Greens

Like any other urban centre, urban greens in Kolkata comprise an extensive range of different components – planted forests, parks, tot lots, woodland, street tree and square plantings, avenue planting, green strip, cemeteries, private gardens, community gardens, green roofs, playgrounds, sports complexes, green belts and so forth (Helms 1998). According to Urban Development Plans Formulation and Implementation (UDPFI) Guidelines (Ministry of Urban Affairs and Employment 1996), the percentage of this recreational space to total developed area needs to be 12–14% for small towns, 18–20% for medium and small towns and 20–25% in case of million plus cities; but for the city concerned, it is only around 15%.

6.7.2 Urban Greens and Forests Within Kolkata

Tree plantation was initiated since the inception of Calcutta Municipal Corporation in 1727 (Kolkata Municipal Corporation 2020). Initial tree plantation was mainly adopted by the local residents, which soon gained importance. Planting of trees along the streets of Kolkata officially started in the year 1869 (Goode 1916). Thereafter, successive legislature made provisions to facilitate the planting of trees within the city of Kolkata. In the early eighteenth century, Maidan and Eden Gardens were created along with Dalhousie square and other large park and greens. Conservators were appointed by the corporation during 1905 for maintaining the greens in public places involving arboriculture (Kolkata Municipal Corporation 1997). In 1911, after the establishment of Calcutta Improvement Trust (CIT), the brainchild of Lord Curzon, stressed on expansion and improvement of Kolkata and its surroundings which mainly included parks and open spaces (Kolkata Improvement Trust 2015).

Historical facts have suggested a fair share of vegetation cover in and around Kolkata. The paleontological evidences of the peat depositions which was found at a depth of 70 to 80 feet in and around Kolkata found in and around Kolkata at a depth of 72–82 feet have revealed the presence of both arboreal and non-arboreal pollen types, the latter comprising both wild and cultivated grass of fluctuating concentrations (Nair 1986). Studies have shown that the Sundari trees have been found in different parts of Kolkata at the very initial stages. During 1702, the East India Company had built floristic rich gardens encircling the ponds (Ghosh et al. 2013). The growth of the city has been unplanned and haphazard, thus leading to clearing of the green cover. The British period saw much of clearing of forest for expanding settlement and construction of roads. During 1790, much of the forests were cleared for giving a new cityscape for the then Calcutta (Ghosh 1988). The first detailed documentation of vegetation of Kolkata was carried out by Benthal (1946), who provided a comprehensive account about the location, characteristics and evolution of the trees available (enlisting 276 varieties) in the then city and its neighbourhood. At a later date, Ghosh (1991) and Ghosh et al. (2013) threw light on the status of urban vegetation of Kolkata, highlighted the ecosystem services rendered by them and compared the present situation with that of the Benthal's time – identifying that almost 56 species (21%) have disappeared from the city's urbanscape and emphasised on the need of conserving the species.

The largest patch of green which have been maintained since the colonial times is the 'Maidan' area, central Kolkata, which is popularly referred to as 'lungs of the city'. The other prominent green spaces are Rabindra Sarobar Lake with its adjoining greenery in Southern Avenue, Agri-Horticultural Society of India and Alipore Zoological Garden in south Kolkata, the grounds of Raj Bhavan in central part of the city and green patches in and around eastern Kolkata along East Kolkata Wetlands (Dhali et al., 2019). Besides there are several parks and squares of varied dimensions, but these cannot be really referred to as forests but mere UGS which have been carved out. In case of the city of Kolkata, there is no official presence of urban forest. But on a 1-kilometre stretch of land in south Kolkata between Majherhat and New Alipore along the railway line spanning over two decades, on personal initiative a lawyer, Mantu Hait planted around 30,000 trees, encompassing over 250 varieties – mostly fruit-bearing ones (The Better India 2019).

Atal Mission for Rejuvenation and Urban Transformation (AMRUT) was launched by the Ministry of Urban Development (MoUD) in June 2015 through which initiatives were taken to develop green spaces within the cities aiming to increase the green cover by 15% in a period of 5 years under the aegis of Urban Local Bodies (Ministry of Housing and Urban Affairs 2019). The areas on which Department of Municipal Affairs, Government of West Bengal emphasised were sanctioning building plans of new housing, industrial and other related projects only if they had a minimum provision of 15% of tree cover in the form of dedicated open spaces and planation of trees along the driveways, creating sufficient nurseries for good-quality planting stocks and also taking efforts in protecting the existing greens. The scheme also noted that to improve the urban quality of life, recreational urban forest can be developed in the peripheral areas identifying suitable large blocks of land. Scholars like Teng et al. (2011) emphasised on integrated green space planning involving recreation and conservation side by side. This sort of approach is needed for Kolkata too to do away with the gross areal disparities and ensure somewhat equal access to greenery for all its citizens.

6.7.3 Identifying Loopholes in Existing Urban Greenery Management Practices

Several steps have been taken by all stakeholders to improve the green quotient of the city, but the yielded results have not been much promising. From the prolonged field observations, quite a few glaring issues were identified:

Type of trees chosen. The policy of 'right place, right tree' needs to be followed while selecting the tree species keeping few criteria in mind – fast-growing, low-maintenance, wind-resistant, deep-rooted, robust ones are most appropriate taking into account the varying soil and climatic conditions. But often, aesthetic preference takes over the other important factors.

Spacing of trees. There is no stringent norm about tree spacing as it depends of the tree species and the type of area where the plantation is carried out. However, for avenue trees, the general convention is 10–12 m of spacing.

Unscientific pruning of trees. Regular pruning is done for the tree branches to maintain a manageable height and also to make way for overhead utility lines, but often it is done in a lopsided manner by untrained workers affecting the shoot ratio for which the roadside trees are unable to stand strong winds.

Concretisation of pavements. Of late, a number of Urban Development Authorities and Urban Local Bodies have undertaken large-scale concretisation of pavements which has resulted in restricted growing space of the root zone of a number of roadside tress by first rendering them weak lives and consequently making them easy prey for uprooting during norwesters or gusty storms, apart from damaging the foothpath itself. If situation demands, pervious tiles can be used for the purpose leaving the root zone uncemented.

Maintenance planning. It starts with creating nurseries from where economical large-scale planting of selected species could be done. After planting of seedlings in suitably soiled pits – regular watering and periodic manuring need to be done for healthy growth; then constant supervision is essential for removal of parasites and unhealthy branches. Modernised technology of transplantation of trees needs to be emphasised more, trying to improve the survival rate, in urban areas where due to large-scale constructional activities, often, full-grown trees are chopped off.

Involvement of stakeholders. Since all the burden cannot be borne by the governmental agencies, there is need for private players to chip in in creation and maintenance of urban parks too. In the new urban housing development, a part of the project area and estimated project cost has to be earmarked for green landscaping. Public participation is another aspect which is weak, active participation of residents, large private landholders, engineering professionals and non-governmental organisation are needed to play the role of catalyst to develop a common vision and review the versions of the plan.

Lack of comprehensive documentation. There is dearth of detailed information about UGS both quantitatively and qualitatively, regarding species type, age, recent condition, etc. which stands in the way of further planning regarding urban greenery. There is a dire need of an inventory of urban biodiversity for proper monitoring and planning.

To remove the above said obstacles, help of a central organisation might be sought with experienced members who can advise the state and local agencies about horticulture and landscaping. To maintain adequate green cover, ecological development of the city has to imbibe certain conscious efforts from urban local bodies even in some cases through legal provisions like imposing building codes, etc.

6.7.4 In Search of Amendments: Emerging Urban Forest in the City Fringes

In 2020, on the occasion of World Environment Day, the Ministry of Environment, Forest and Climate Change announced the Nagar van scheme to develop 200 Urban Forests across the country in next five with governmental collaboration funded by Compensatory Afforestation Fund Management and Planning Authority and supported by people's participation to nurture 'lungs' in congested urban areas (Ministry of Environment, Forest and Climate Change 2020). For Kolkata, to mirror such initiatives, open spaces were hard to come by in the main city, so the satellite townships were the areas offering better living quality with probable planned green spaces. Several such sub-cities have been proposed by Kolkata Metropolitan Development Authority in The Perspective Plan of Kolkata which includes New Town, Rajarhat, Bidhan Nagar (popularly known as Salt Lake), Kalyani, West Howrah, etc. with large share of the land earmarked as UGS in the master plans. The planning of UGS in New town became a key concept with the growing urban sprawl. It aimed at connecting the greens at sector level and the neighbourhood through walkability.

New Town, Rajarhat, the fast-growing satellite city of Kolkata, is now referred to as 'Green City' as it encourages an eco-friendly lifestyle in an urban area maintaining the balance between urban development and environment (Ahern 1995). The 480 acre of land and 112 acres of water body have been transformed into a well-maintained eco-park established in 2012. 99 different species of plants are found in the eco-park including tropical tree garden, rose garden and bamboo garden (West Bengal Biodiversity Board 2019). With an aim to increase the green cover, the Housing Infrastructure Development Corporation (HIDCO) has planned to set up an urban forest over an area of 7 acres of land in Action Area II. HIDCO and New Town Kolkata Development Authority (NKDA) have been planning strategies for plantation.

Urban afforestation and beautification have been continuing for a long period. The government of West Bengal has considered a comprehensive Plan of Action to meet the challenges of rapid urbanisation under the project 'Green City Mission'. The project aims at urban greening along with 'Blue-ing' by conserving water bodies, waterfront greening and beautification (Urban Update 2020).

The tropical cyclone Amphan (16 May. 2020) shattered Kolkata with heavy rains and strong winds uprooting more than 4000 trees (Times of India 2020), which made the planners more concerned about the proper species selection for venue plantation; to sustain the gusty storms, slender trees like rosy trumpet and foxtail are being preferred (The Telegraph 2021). Trees like neem, betel nut, coconut and palm were considered for plantation. Besides, planting of grape fruits and guava on open lands was also decided by NKDA (Millennium Post 2020). About 3738 trees have been restored in New Town, and the State Pollution Control Board has also taken the initiative to plant 2000 trees on HIDCO land emphasising on species like neem, arjun, palash, kadamba and Ashoka (Times of India 2020). Slender and flexible trees have been planted in New Town. Palm, cherry blossom and coconut trees, which are less likely to topple down, have been planted along the median divider and sidewalks. HIDCO along with the forest department has come up with plantation planning in New Town where considering the soil character, two types of plantation have been sought of, one resilient to storms and the other to air pollution.

New Town has come up with the unique idea of creating an urban man-made forest for a sustainable environment and which enables urbanites to connect with nature (Fig. 6.9). The initiation of creating an urban forest over 4 acres of land near Tall Tree nursery, Rajarhat has been taken by HIDCO along with the NGO Green for Life Foundation and the Forest Department. More than 700 trees have been planted which included saplings like *Bokul*, *Krishnachura*, *Akashmoni*, *Neem*, etc. A fair number of rubber trees have been planted. Over 8000 trees have been planted which will make a huge difference in absorption of carbon dioxide and help in wildlife conservation (Biswas 2018).

6.8 Conclusion

The rapid and uncontrolled urbanisation is the major source of the environmental degradation and decline in the green spaces within the city of Kolkata. Unparalleled population growth, changing climate, migration and expansion of infrastructure translate the green scenario of the urban areas. This research work is thus a snapshot of the effects of land use-land cover change and the continuous decrease in the urban green space within the city hindering the sustainable urban development. Green spaces are an indispensable component of a built environment. The presence of green spaces is an indication of better health and social wellbeing which also helps in controlling climate change (Tu et al. 2016). Thus, protecting and preserving the greenery within the urban city is of utmost necessity.

In the developing countries, there are extensive areas where low-income residents live in congested neighbourhoods without much option of open or green spaces; so, provision of green walls and roofs can help in cooling the microclimate of the area. Curtis et al. (2014) flagged caution about the tree species emitting Biogenic Volatile Organic Compounds (BVOCs), but Singh et al. (1998) pointed out that in Indian cities, there are several such ornamental avenue trees which emit isoprene (a common VOC), and those need to be omitted from future plantation programmes. While shortlisting the suitable species, Air Pollution Tolerance Index (APTI) and Particulate Abatement Capacity (PAC) can be used as important indicators especially for roadside plantations to abate the air pollution preferring species like *Ficus benghalensis*, *Mangifera indica* and *Carissa carandas* (Kuddus et al. 2011).

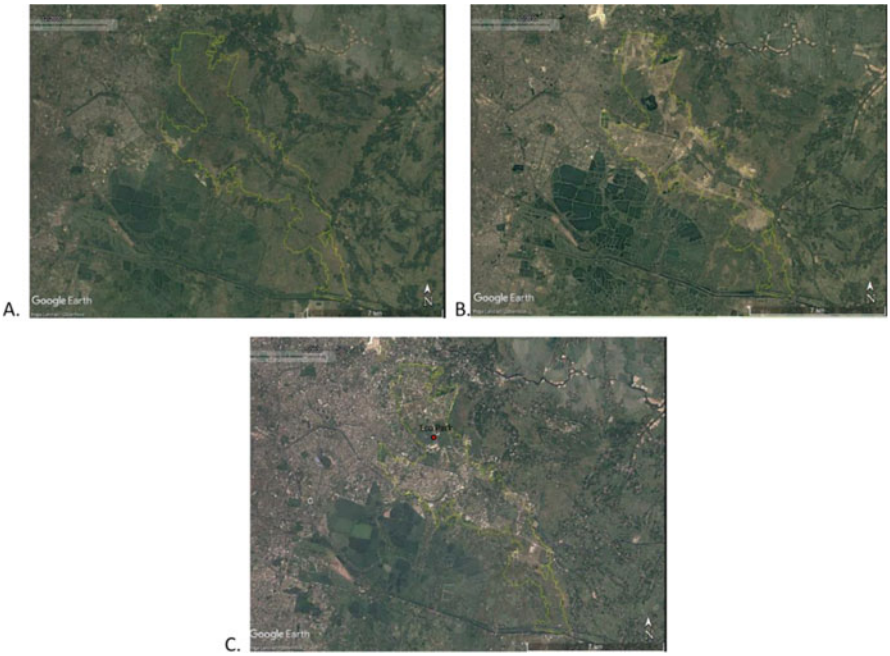

Fig. 6.9 Growing urbanising trend identified with the help of Google Earth images (A, B, C) of 2000, 2010 and 2020 corroborating the presence of distinct green cover along with the marked presence of Eco Park in New Town, Rajarhat area

The management of urban green spaces which are constant under the scrutiny of the public eye needs to be transparent and efficient. But a lack of up-to-date detailed inventory of urban forests and other greeneries in the cities often leads to insufficient financial allocation for maintenance and further expansion. To increase the urban green space, integration of green patches has to be made at different levels following a certain hierarchy; in the master plans of cities, maintenance of ecological balance has to be prioritised with provisions for green belts-corridors and social forestry in the derelict lands. To reduce the impact of air pollution due to heavy traffic, regulated, selective greening of transport corridors may be attempted. As per Town and Country Planning Organisation (2014), the ones which are recommended to be highly avoided for urban planation are the ones with weak stem which are prone to easy breakage during windstorms and cause accidents like *Eucalyptus* and the thorny varieties which might cause injury to the children and lead to tyre leakages.

On the 4th of July 2016, the concept of Green City Mission for Kolkata was approved by the Urban Development and Municipal Affairs Department. The main areas of concern for it were to increase green areas, conserve water bodies and beautify public spaces. The schemes were widely accepted by the Urban Local Body, but the issue of maintaining the assets has been widely debated as most of these greening schemes are not revenue generating. The scope of involvement of private players is being thought of through development of theme parks (New Town Kolkata Developmental Authority 2019).

As per guidelines of UDPFI, Government of India, protection of open spaces is of utmost importance from ecological and social perspectives. The current metropolitan development plans include mandatory green spaces within their schemes. The urban greenery models can be modified to suit the context of the city of Kolkata, India, in planning patches and stretches of urban forestry keeping the balance between developmental needs and environmental concerns. Proposals have been there for establishing a separate section dealing with urban forestry within the designated forest regulating authority for better management.

But there has been a kind of lack of comprehensive planning for urban forestry in developing countries like India, and especially for Kolkata, there is lack of detailed urban forestry-related database and research which puts the city in a tight spot (Pataki et al. 2011). Besides, there is inadequate financial support, nominal budgetary allocation and bureaucratic red-tapeism for urban forestry programme which pose a problem for systematic expansion. If the ecological services provided by the urban forests can be tapped, then the promised economic return will augment the municipal investment in this green infrastructure (Sharma et al. 2009). There is lack of skilled researcher in the said field for which networking with seasoned academicians would help in streamlining the programmes of urban forestry.

Moreover, in a diverse megacity like Kolkata, it becomes fairly tough to find space for development of urban greens. Rapid urbanisation coupled with the increasing population is making the situation tough as green spaces are at the verge of extinction. The paper has been an attempt to assess the urban green space scenario of the city of Kolkata along with a treescape and person-park ratio. A skewed distribution from person-park ratio can be identified which might help planners increase the number of parks where the ratio is less favourable. The methodology also highlights the area where vegetation cover is showing a declining trend, thus indicating a risk zone. This might help the planners allocate the resources accordingly. The treescape is a tool that might help planners focus on green assets of the city and consequently plan the strategies. The ease of computation makes it advantageous for easily adopting this method by planners and policymakers for a sustainable development.

The urban environment is continuously developing and growing. Urban greening has become incredibly important for various reasons. Urban forests are fundamentally human dominated, and therefore, the role of human beings is critical. The level of education and environmental awareness of the urban residents play a major role in determining the composition, management and overall development of urban forest. Thus, urban greenery development not only relies on technology and investment but largely depends on the attitude and involvement of the residents. Registering and intermittent monitoring of urban trees besides expansion of green spaces, while formulating infrastructure-related policies, can improve the urban forestry status. Thus, nurturing community-based programmes might be beneficial. The perception study highlighted people's willingness to protect the green cover in the city. Strengthening the green cover from household to neighbourhood to the city level will lead to a stable environment.

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Chapter 7
Forest Resource Scenario in Industrial Town: A Study of Asansol-Durgapur Region

Jaidul Islam, Partha Pratim Sarkar, Abdur Rahman, and Ram Avtar

Abstract Indisputably forest is one of the most significant natural resources and one-third of the land area of India is covered by forest which not only contributes extensively to the social and economic well-being of the rural people but also assures the sustainable growth of urban development through the preservation of the urban environment. However, in recent times, forests are being destroyed in the name of development, and the conversion of woodlands to others is an acute problem in India. At the same time, due to the lack of proper monitoring, these problems are increasing day by day. Statistical data on forest cover in India demonstrates the fact that - the destruction of forest cover largely depends on industrialization and urbanization. Asansol-Durgapur region of India is experiencing industrialization followed by urbanization in the last few decades. Though many studies have been conducted on the urban and industrial growth of the Asansol-Durgapur region, considering the importance of forest resources in the area. However, there is a substantial research gap in the study of the forest resource scenario of the study area. This study is an attempt to assess the forest resources management scenario of the Asansol-Durgapur (Industrial towns) region using geo-spatial technology. To conduct this study, satellite images of different periods for the study area have been acquired and analyzed. Different vegetation indices (e.g. Normalized Difference Vegetation Index, Soil Adjusted Vegetation Index), Land surface temperature (LST) have been derived to understand the nature and dimension of forest cover change in the study area. Supervised image classification of Landsat imageries from 1991 to 2021, measured the forest concentration in the study area, and correlated with the LST. The results show the reduction of sparse vegetation area (–34.201%),

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protected forest (−6.504%), and cultivated land (−26.142%), in the last 30 years. Similarly, maximum expansion is of opencast coal mining, industrial area, and, the built-up area also observed in the study area. The result also reveals that the loss of green area increases the surface temperature in Asansol and Durgapur industrial towns. Both the Asansol and Durgapur regions have recorded an increase of maximum and minimum land surface temperature from 31.64 °C to 39.64 °C and 18.83 °C to 24. °52 C respectively from 1991 to 2021. The overall study reveals that the forest cover of the study area declined due to, urbanization, and industrialization activities.

Keywords Forest cover change · Industrial town · Urban green space · Land Surface Temperature

7.1 Introduction

Forest is, an important natural resource and the greatest charity of nature to human civilization. It's home to the maximum world's terrestrial biodiversity (FAO and UNEP 2020a, b). Benefits that are available from forest resources vary from fuel for heating or cooking, raw materials for industrial needs, protection to watersheds to enable hydroelectric generation, carbon sequestration, climate amelioration, soil and water conservation, and recreation (Kumar and Saikia 2020). Besides, forest helps to bring rain, provide a clean air supply for the living creatures (FAO 2015). Forest in different forms is interlinked to a socioeconomic factor and sustaining ecological services from the very beginning (Munsi et al. 2012). Considering the global forest cover statistical data, it is observed that almost 31% of global land is covered by forest, though forest cover is not equally distributed over different countries, around 66% of the total forest is found only in ten countries (FAO and UNEP 2020a, b). Currently, deforestation has evolved as a very serious issue all over the world (Sahana & Ganaie 2017; Sahana et al., 2018). The forest cover has been changed due to several anthropogenic factors like furtive deforestation, overgrazing, increasing agricultural, etc. (Barakat et al. 2018). In the name of development, industrialization, and urbanization, forest covers are unconsciously or sometimes consciously eliminated (Pokhriyal et al., 2020). The rate of deforestation can be further correlated with the level of urbanization and industrialization in different countries of the world (Cuba et al. 2014; Li et al. 2016). In a developed country, the rapid rate of urbanization is the major cause of deforestation. In the case of developing countries like India, the major problem of deforestation is due to the rapid increase in population. Since 1990, approximately 420 million hectares of forest cover have been pulled down and converted to other land cover types (FAO and UNEP 2020a, b). Changes to forest cover can result in a variety of negative environmental consequences (Fuwape 2003; Malek et al. 2015). Deforestation can affect water balance and can increase the erosion rate, which directly affecting the landslide activity (Ghimire et al. 2013). Besides, deforestation is threatening the environment (Duguma et al. 2019), as it leads to a rise in the land surface temperature, soil erosion rate, flood frequency, etc.; (Zheng 2006; Laurance 2007) decrease the rate of precipitation; affect the soil productivity; and ultimately creates disequilibrium in the ecosystem (Saxena 2010).

India is a tropical country, and it is expected that in 2030, the population of India will reach nearly 1.5 billion (Munsi et al. 2012). In India, the forest occupies one-third of the Earth's land area (FAO 2015). Whereas in West Bengal total forest cover is 16847 sq. km which is 18.98 percent of the total geographical area (Forest Survey of India 2019, MSME 2019). The economic history of the Paschim Bardhaman district of West Bengal begins with industrialization where its two sub-divisions namely Asansol and Durgapur earn widespread geographical popularity, were previously a part of the Burdwan district. The historical tale of this industrial district extensively revolves around its dense forested area, which was the extended part of the forest area of the Dumka district of Jharkhand. This part maintained the security of its forest cover until the discovery of Coal followed by the industrialization in this area in the late 19th century (MSME 2018). Asansol Durgapur Development Authority (ADDA) has acquired land of the district for infrastructural development to promote industrialization and construction of the industrial complex in the area (MSME 2019). Maximum industrialization of Paschim Bardhaman took place along NH 02 of the Asansol and Durgapur region. Industrialization in the Asansol Durgapur region leads to rapid immigration of industrial skilled and unskilled labor which directly affects the pace of urbanization. The vicious cycle of industrialization, population growth, and urbanization leads to deforestation in the area. Like any other industrial town, the Asansol-Durgapur region also badly suffers from the abolishment of forest cover for the rapid growth of urbanization which changes the LULC pattern rapidly in the area (Choudhury et al. 2019). The forests in this region are very fragmented. In the last three decades, forest cover has been vulnerable only because of encroachment of the periphery for settlement construction, road line formation, and alternation of land use due to the population growth (Dutta et al. 2020). Nowadays, this region reported heat island phenomenon due to the degradation of forest cover (Choudhury et al. 2019). The huge destruction of the forest and deforestation due to mining and industrialization has badly affected the lives of the people of this district (Mukhopadhyay et al. 2014). The forest resource of Paschim Bardhaman district and the green density of Asansol Municipal Corporation and Durgapur Municipal Corporation demands the spatial attention of the researchers (Das et al. 2020; Rehman 2020). To assess the effect of the shrinkage of urban green space over time in these municipal corporations is relevant in the context of environmental sustainability and policy recommendation.

Many researchers have already noticed the problems of deforestation globally in the late twentieth century. So, there is a wide range of literature available that deals with forest cover change detection and environmental impact due to deforestation. Being the apparent subject of sky-high prosperity along with economic advancement due to rapid industrialization and flourishing urbanization, the Asansol Durgapur region is implicitly a tragic victim of excessive deforestation. Hence, keeping in mind the geographical importance of forests as well as the pernicious consequences of the destruction of woodlands in the Asansol Durgapur region. This region has been taken into account as the study area.

The present work is an attempt to trace the actual scenario of forest resources of the Asansol Durgapur industrial region and try to identify the changes of land use-land cover from 1991 to 2021. At the same time, this work also tries to measure the dynamics of urban green space and its eventual effect on urban land surface temperature. This research provides a broad idea about the forest cover change and its impact on the environment. Various researchers have done individual research on forest loss and LST, but no comparative assessment has taken place in this study area. In this study comparative assessment of two regions has been done, making this paper even more significant. The paper finally strives to propose recommendations on and policy suggestions for the sustainable persistence of forest cover in the area.

7.2 Study Area

Paschim Bardhaman is a predominantly mining and industrial district of West Bengal formed on the 7th of April 2017 with a 1602.17 sq.km geographical area from the erstwhile Bardhaman district (Govt. of West Bengal, 2021). The geographical extension of the district is 23°22′30″ North to 23°53′59″ North and 86°46′25″ East to 87°29′03′ East (Fig. 7.1). This district is comprised of two subdivisions, namely, Asansol and Durgapur, and eight blocks (MSME 2019). Paschim Bardhaman district is bordered by Dumka district of Jharkhand and Birbhum district of West Bengal in the north and northeastern side, whereas Bankura district and East Bardhaman district are located in the south and southeastern part of the district. The rivers Ajay and Damodar have encircled the district to the north and south

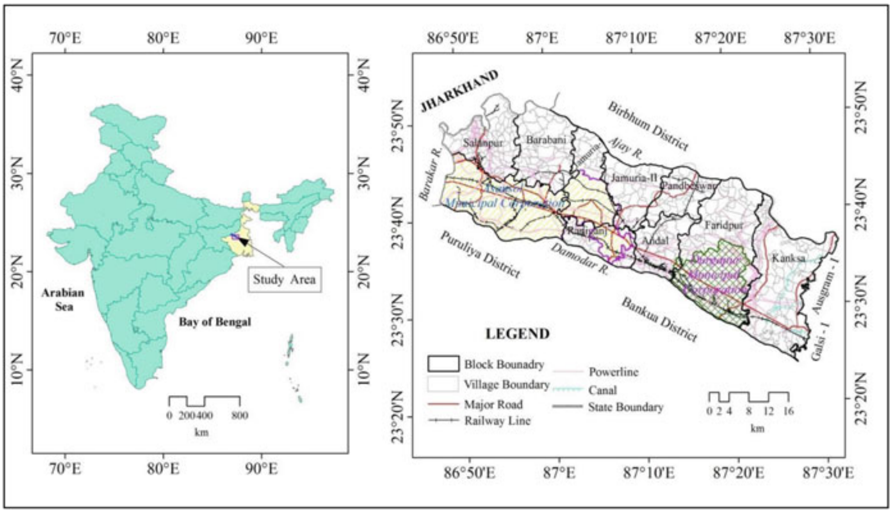

Fig. 7.1 Location of the study area

respectively. The climate of this region is characterized by high temperatures in summer, low to heavy rainfall in the monsoon. The maximum and minimum temperature during the summer and winter periods is 44 °C and 05 °C. The average annual rainfall of this region is 1408 mm (Choudhury et al. 2018). The soil characteristics of this region are of three types, viz., lateritic ultisol, red and yellow ultisol soil, and alfisols older alluvium soil. The maximum part of this region is comprised of red and yellow types of ultisol soil (Ghorai et al. 2014). As already mentioned, the district of Paschim Bardhaman is an industrial region, and around 50% of the land is used for non-agricultural purposes in the district. The district has 12% area under forest which is below ideal. The greater segment of this region is covered with wet deciduous forest type where Sal (Shorea robusta) is categorized as the principal species. Predominantly three types of forest are traced over this re, including dry peninsula Sal forest, northern dry mixed deciduous forest, and dry deciduous scrub (Champion & Seth 1968).

7.3 Materials and Methods

Landsat 5 TM and Landsat 8 TIRS-OLI satellite imageries acquired in 1991 and 2021 were used to analyze the dynamics of the forest cover of the Paschim Bardhaman district. Detailed descriptions of satellite imageries are followed by the USGS Landsat data manual (USGS 2019). Two different years, e.g., 1991 and 2021, have been considered for this study, for understanding the change of forest cover. LULC map has been prepared using supervised image classification using the maximum likelihood technique. The Landsat data were classified into 9 classes based on dominant LULC types. Classified images were validated using Google earth image and field verification. Several research works are found to have different types of vegetation indices (NDVI, SAVI, etc.) for assessing the health of vegetation, vegetation cover, etc. (Labib et al. 2020a, b; Janssen et al. 2018; Kriegler et al. 1969; Rouse et al. 1974; Huete 1988; Huang et al. 2021). This study has adopted two indices, e.g., NDVI and SAVI, for measuring forest resources. To surpass the influence of soil brightness on the Normalized Difference vegetation Index (NDVI)), a Soil Adjusted vegetation Index (SAVI)) has been used in this study. Field observation derived that there are so many spaces in the study area where vegetation cover is very low; for those spaces, only NDVI is not sufficient to get an idea about the forest cover; rather SAVI may open up the reality. LULC and NDVI have been used to investigate the forest cover losses and forest degradation in the protected area. For assessing the importance of urban green space on urban climate, Land Surface Temperature (LST) has been calculated and correlated with the NDVI (Yin et al. 2019). This gives an idea of how forest cover and LST changes are taking place in the study area. The urban green space of Asansol Municipal Corporation (AMC) and Durgapur Municipal Corporation (DMC) is also derived to understand the natural cooling capacity of the area. The following flow chart (Fig. 7.2) shows the logical progression of the work.

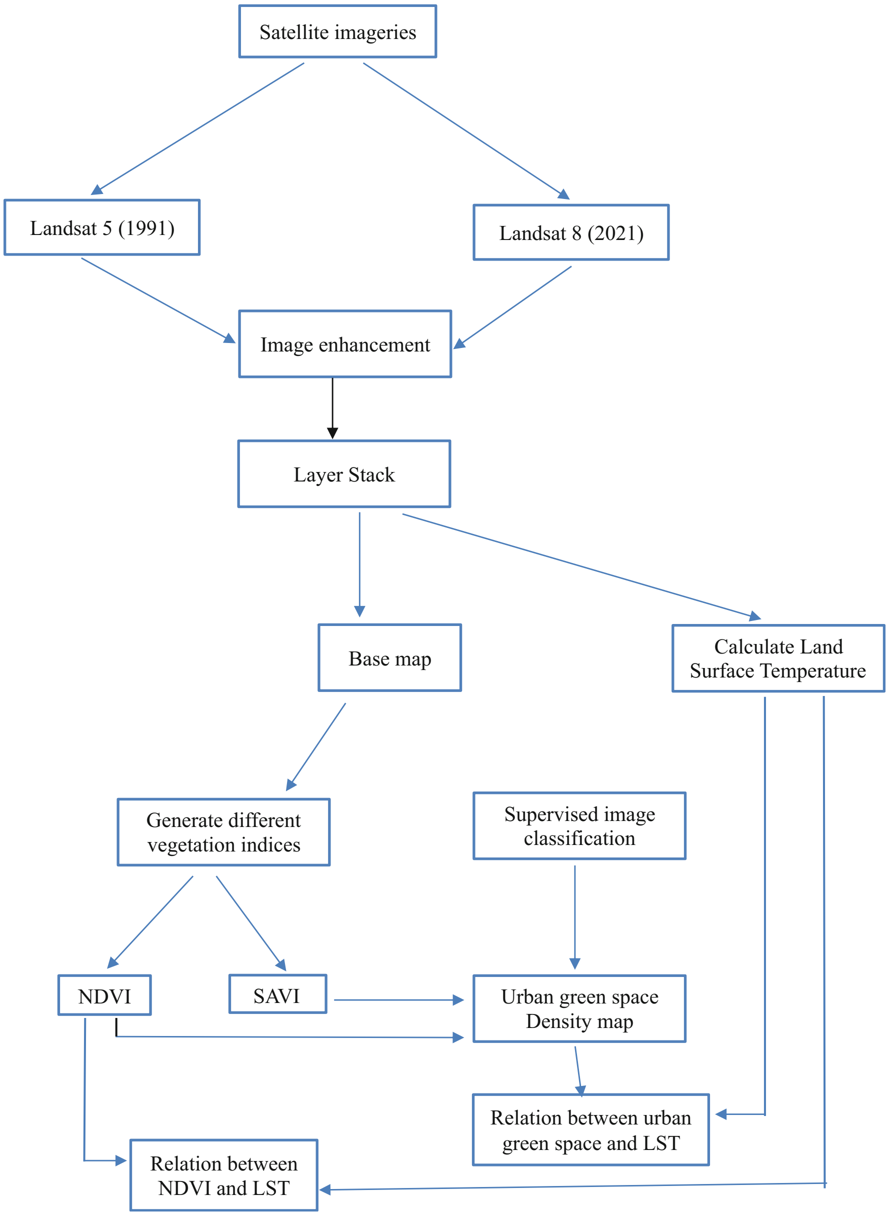

Fig. 7.2 Flow chart of the spatial analysis

7.3.1 Accuracy Assessment

Accuracy assessment is an important tool that helps to correct classification errors. Consequently, an accuracy assessment index involved with a lucid description of the sampling design (including samples volume and details of stratification), an erroneous matrix, every categorical area or proportion of the area according to the map and narrative precision such as users, producers, and overall accuracy, is usually accompanied (Olofsson et al. 2013). Accuracy shows how closely the results are related to the actual values. User's and producer's accuracy were derived by an error matrix of referenced data. To check the validity, presumed random 100 sample sites have been selected from Google earth and crosscheck them concerning the LULC map for verification. Accuracy assessment has been done using the following equations:

$$\text{Overall accuracy }(\%) = \frac{\text{Total number of correct samples}}{\text{Total number of samples}} \times 100 \tag{7.1}$$

$$\text{Producer's accuracy }(\%) = \frac{\text{Diagonal value of Column}}{\text{Column Total}} \times 100 \tag{7.2}$$

$$\text{User's accuracy }(\%) = \frac{\text{Diagonal value of Row}}{\text{Row Total}} \times 100 \tag{7.3}$$

Another method for measuring the accuracy is kappa coefficient (K) (Foody 1992). The value of kappa varies from 0 to 1, where 0 (zero) represents the worst and 1 (one) represents the best. K for 2 different years has been calculated for this study to get the accuracy of the maps. This study has obtained a kappa accuracy of a value above 0.85 for both years (Table 7.1). As per the suggestion made by kappa's value, beyond 0.85 represents excellent accuracy between those two images. Kappa coefficient is derived by the following equation:

$$\text{Kappa coefficient (K)} = \frac{\frac{\sum a}{N} - \sum ef}{1 - \sum ef} \tag{7.4}$$

where '*a*' is Diagonal frequency

'*N*' is the total number of frequencies
Expected frequency (ef) is calculated using the following equation:

$$\text{ef} = \frac{Row\ total \times Column\ total}{N} \tag{7.5}$$

Table 7.1 Accuracy assessments of land use land cover classes

Year	Land use category	Fallow land	Sand dunes	Sparse vegetation	Open-cast coal mining	Industrial area	Cultivated land	Water body	Build-up area	Protected forest	Total	User's accuracy	Kappa coefficient
1991	Fallow land	10							1		11	90.90	**0.89**
	Sand dunes		6								6	100	
	Sparse vegetation	1		10			2				13	76.92	
	Open-cast coal mining				8						8	100	
	Industrial area			1		9					10	90	
	Cultivated land						16				16	100	
	Water body		1	1	1			7			10	70	
	Buildup area	1							12		13	92.30	
	Protected forest									13	13	100	
	Total	12	7	12	9	9	18	7	13	13	100		
	Producer's accuracy	83.33	85.71	83.33	88.88	100	88.88	100	92.30	100			
	Overall accuracy	**91%**											

Year	Land use category	Fallow land	Sand dunes	Sparse vegetation	Open-cast coal mining	Industrial area	Cultivated land	Water body	Build-up area	Protected forest	Total	Users accuracy	Kappa coefficient
2021 2021	Fallow land	7					2		1		10	70	
	Sand dunes		7						1		8	87.50	
	Sparse vegetation			10			2				12	83.33	
	Open-cast coal mining				9						9	100	
	Industrial area			1		10					11	90.9	
	Cultivated land						15				15	100	**0.88**
	Water body		1		1			6			8	75	
	Buildup area	2							13		15	86.66	
	Protected forest									12	12	100	
	Total	9	8	11	10	10	19	6	15	12	100		
	Producer's accuracy	77.79	87.5	90.9	90	100	78.94	100	86.66	100			
	Overall accuracy	**89%**											

7.3.2 Normalized Difference Vegetation Index (NDVI)

Several mathematical algorithms related to vegetation indices have been proposed by various researchers for investigating the health of vegetation cover, nature of forest cover change, distribution of forest, rate of deforestation, climatic change, and its effect on vegetation and society (Keenan 2015; Huang et al. 2021; Ghebrezgabher et al. 2016). NDVI is the simple band transformation of two bands – near-infrared and red (E.7.6) (Kriegler et al. 1969; Rouse et al. 1974).

$$\mathrm{NDVI} = \frac{(\mathrm{NIR} - \mathrm{RED})}{(\mathrm{NIR} + \mathrm{RED})} \tag{7.6}$$

7.3.3 Soil-Adjusted Vegetation Index (SAVI)

SAVI is considered a vital index to monitoring the green area. It is used to reduce the impact of soil brightness reflectance in vegetation indices (Huete 1988). SAVI is integrated as a modified method of NDVI to correct the effect of soil brightness where vegetation is minimum and sporadic (Qi et al. 1994; Candiago et al. 2015). Usually, this index depends on red and near-infrared bands, and the algorithm used for SAVI is shown in (7.7) (Huete 1988).

$$\mathrm{SAVI} = \frac{(\mathrm{NIR} - \mathrm{RED})}{\mathrm{NIR} + \mathrm{RED} + L} \times (1 \quad + \quad L) \tag{7.7}$$

where L is a constant. If $L = 0$, then SAVI $=$ NDVI, in general, most of the cases taken $L = 0.5$

7.3.4 Land Surface Temperature (LST)

LST is popularly used by various researchers for assessing the effect of forest destruction and shrinkage of urban green space on urban heat islands (Kumari et al. 2018; Sahana et al. 2019; Prevedello et al. 2019; van Leeuwen et al. 2011). In this study, for the calculation of surface temperature, band 5 of TM sensor and Band 10 and Band 11 of OLI/TIA sensor have been used (Sahana et al., 2016). This study has also calculated LST based on NDVI with the following steps:

Step-I Conversion Digital number to radiance

$$L\lambda \frac{(l\max\lambda - l\min\lambda)}{dx(Q\mathrm{calmax} - Q\mathrm{calmin})} \times (Q\mathrm{cal} - Q\mathrm{calmin}) + l\min \tag{7.8}$$

where $L\lambda$ = spectral radiance at the sensor's aperture in (Watts/(m^2 × sr × μm)); Qcal = quantized calibrated pixel value in DN; Lminλ = spectral radiance scaled to Qcalmin in (Watts/(m^2 × sr × μm)); Lmaxλ = spectral radiance scaled to Qcalmax in (Watts/(m^2 × sr × μm)); Qcalmin = minimum quantized calibrated pixel value; *and* Qcalmax = maximum quantized calibrated pixel value.

Step-II Conversion Radiance to brightness (Temperature in degree Celsius)

$$\mathrm{BT} = \frac{K_2}{(\ln(K_1/1\lambda + 1))} \tag{7.9}$$

where BT = brightness-temperature; K_2 = calibration constant 2(1260.56); $\square_1$ = calibration constant 1(607.76); lλ = spectral radiance in (Watts/(m^2*sr*μm)

Step III: Calculation of LST:

$$LST = \frac{BT}{\left(1 + l\lambda\left(\frac{BT}{p}\right) \times \ln(e)\right)} \tag{7.10}$$

where BT = brightness-temperature; $l\lambda$ = top of atmosphere spectral radiance (Watts/(m^2*srad*μm)); $p = h$*c/s = 14,380; and e = surface emissivity

$$e = 0.004 \times pv + 0.986 \tag{7.11}$$

$$\mathrm{PV} = \left(\frac{\mathrm{NDVI} + \mathrm{NDVI_{max}}}{\mathrm{NDVI_{max}} - \mathrm{NDVI_{min}}}\right)^2 \tag{7.12}$$

7.4 Results and Discussion

7.4.1 Dynamics of Land Use and Land Cover

Supervised image classification technique was used for classification of Paschim Bardhaman district for the years 1991 and 2021. Nine types of LULC classes were identified in the study area i.e., fallow land, sand bar, sparse vegetation, opencast coal mining, industrial area, cultivated land, water body, built-up area, and protected forest. The statistics of land use-land cover change from 1991 to 2021 is summarized in Table 7.2 and Fig. 7.3. In the year 1991, cultivated land has covered the maximum area (910.88 sq.km, i.e., 56.34% of total area) followed by sparse vegetation (307.36 sq.km, i.e., 19.01%) and built-up area (187.58 sq.km, i.e., 11.60%) in the year 1991.

Land use-land cover of the study area has been remarkably changed from 1991 to 2021. Cultivated land continuously decreases but still covers the highest, i.e., 672 sq. km, which is 41.66% of total land. The cultivated area lost 238.12 sq.km between the

Table 7.2 Dynamics of land use-land cover in Paschim Bardhaman district

LULC class	1991 Area in sq. km	1991 % of area to total land use area	2021 Area in sq. km	2021 % of area to total land use area	Overall change 1991—2021
Fallow land	36.95	2.29	53.17	3.29	16.22
Sand bar	18.27	1.13	9.82	0.61	−8.45
Sparse vegetation	307.36	19.01	202.24	12.52	−105.12
Opencast coal mining	21.93	1.36	85.21	5.28	63.28
Industrial area	18.66	1.15	51.7	3.2	33.04
Cultivated land	910.88	56.34	672.76	41.66	−238.12
Water body	24.65	1.52	30.29	1.88	5.64
Built-up area	187.58	11.6	424.45	26.28	236.87
Protected forest	90.51	5.6	85.3	5.28	−5.21

Source: Calculated by authors based on satellite imageries

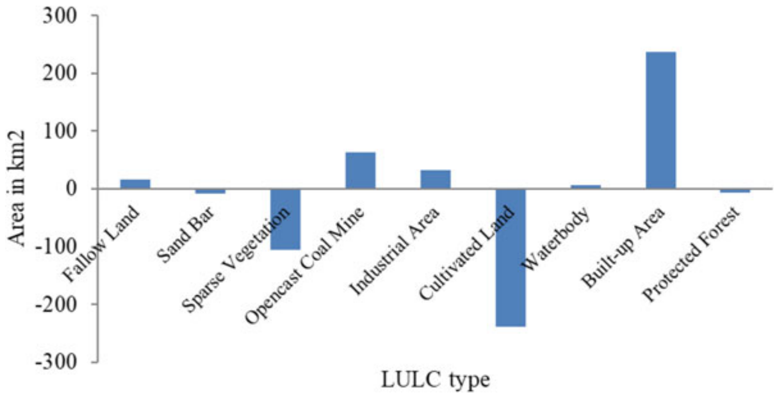

Fig. 7.3 Changing pattern of land use-land cover during the year 1991 to 2021

decades; this land use decreases from 910.88 sq.km in 1991 to 672.76 sq.km in 2021. The sparse vegetation and protected forest recorded a negative change of 6.49 and 0.32%, respectively, between 1991 and 2021 (Table 7.1 and Fig. 7.3). Besides, the built-up area has recorded a huge increase (236.87 km^2) from 187.58 to 424 0.45 km^2 and presently it occupies ~26.58% of the total land area of Paschim Bardhaman district.

7.4.2 *Spatiotemporally of Deforestation and Transformation Forest Area into Other Land Use*

To access the nature of deforestation and vegetation, LULC has been considered (Lambin et al. 2001), and NDVI and SAVI also played a very important roles in accessing the same. In the LULC, forest cover has been classified into two categories, namely, protected forest and sparse vegetation. The government of India defined protected forest as "any forest-land or waste-land which, is not included in a reserved forest but the property of Government, or the forest land which is rightfully owned by the Government. The Government possesses the proprietary rights of forest lands entirely or partially according to the Indian Forest Act, 1927" (GoI 1927).

Whereas sparse vegetation is a combination of grass cover, planted tree cover, street-side tree, gardens, shrub, etc. (Table 7.1 and Fig. 7.4c) depicts the forest scenario of Paschim Bardhaman district for the years 1991 and 2021 which represents the high concentration of sparse vegetation along the southern portion of this district for the successive decades. At the same time (Fig.7.4d) reflects the loss of huge sparse vegetation in said portion of the district. This study finds 309.33 sq.km sparse forest and 90.47 sq.km protected forest in 1991. The overall proportion of sparse vegetation and protected forest area has been decreased with the expansion of

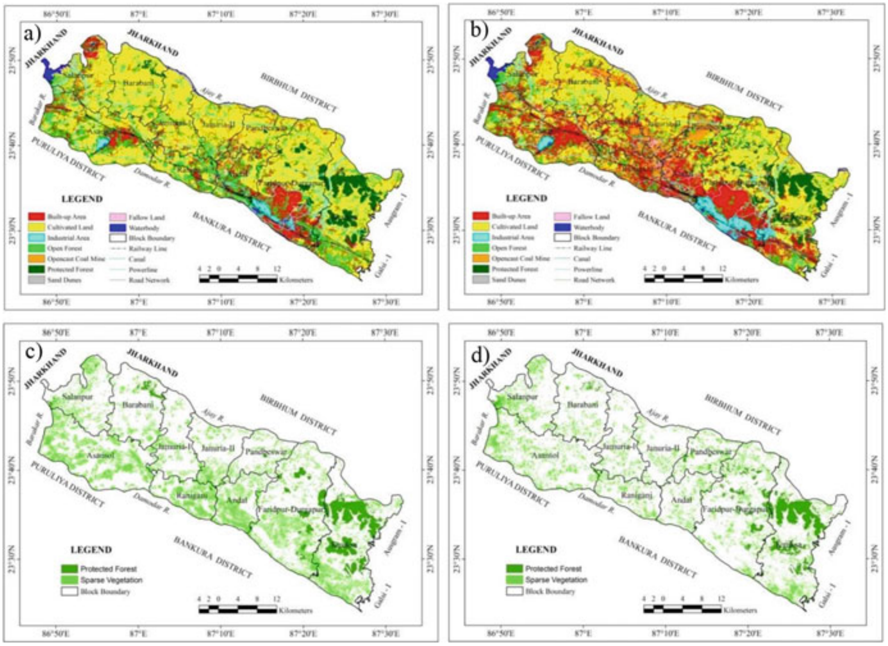

Fig. 7.4 Dynamics of land use-land cover and forest scenario (**a**) 1991, (**b**) 2021, (**c**) forest cover 1991, (**d**) forest cover 2021

urban, industrial, and coal mining areas. Presently, the study area recorded 201.41 sq. and 85.52 sq. km sparse vegetation and protected forest, respectively (Table 7.1). A minute look at the scenario can find that space which was previously sparse vegetation has been converted into a built-up area (131.02 sq.km) followed by cultivated land (54.29 sq.km), open cast coal mining (17.38 sq. km), industrial area (12.10 sq.km), and fallow land (10.64 sq.km), respectively. The study reveals that protected forest has lost its area; about 15.64 sq.km area converted into cultivated land, followed by built-up area (6.73 sq.km), fallow land (1.18 sq.km), industrial area (1.34 sq. km), etc. (Table 7.3 and Fig. 7.4c, d).

7.4.3 NDVI of the Study Area

NDVI is widely recognized in measuring forest health, greenness, the productivity of the forest, and forest cover change (Meneses-Tovar 2011; Gandhi et al. 2015). Many studies have been conducted based on NDVI to monitor the forest resources, landscape changes (Janssen et al. 2018), forest degradation (Meneses-Tovar 2011), etc. In this study area, NDVI value varies from −0.416 to 0.5539 in the year 1991 and from −0.758 to 0.482 in 2021.

The calculated NDVI for the study is further classified into four categories, i.e., very low, low, medium, and high. In the year 1991, it is observed that 12.03% area was under dense forest having threshold value ranging from 0.172 to 0.656; and maximum area (47.45%) comes under medium forest with the threshold value ranging from 0.0795 to 0.171 (Table 7.4). Considering the NDVI value of 2021, it is viewed that 11.762% area has been detected as dense forest (0.200–0.497) and 40% as a less dense forest with threshold value from 0.071 to 0.137, respectively (Fig. 7.5a, b). Both the NDVI of 1991 and 2021 reveal that the proportion of non-forested areas remarkably increased between the decades from 2.481 to 8.661%. In association with this, the analysis also witnesses a rapid reduction of medium forest (from 47.45 to 39.33%) and a slight decrease of dense forest from 12.03 to 11.762%.

In the case of Asansol Municipal Corporation, the calculated NDVI witnessed the presence of stable dense forest over the period (Table 7.5). Table 7.5 further reveals a slight change of forest cover recorded high NDVI from 26.85 to 20.09% over the same period, and the change can further be correlated with the low NDVI which recorded positive changes in the same decades. But when, the NDVI of Durgapur Municipal Corporation (DMC) is considered (Table 7.6), the scenario is quite different. The NDVI of DMC depicts proportionally rapid negative changes of high NDVI which means the amount of healthy vegetation decreased remarkably in the said period. The overall NDVI of the study area prevails the presence of fragmented vegetation cover as the value of NDVI ranges from −0.1 to 0.6 (apparently) which means there is no absolute healthy vegetation in the study area as the NDVI value of 0.6–0.8 can be termed as the presence of healthy vegetation (Bhatta 2020) (Table 7.6).

Table 7.3 Transition matrix of land use-land cover

Land use and land cover type		LULC 2021								
		Built-up area	Cultivate d land	Fallow land	Industrial area	Open-caste coal mining	Protected forest	Sand bar	Sparse vegetation	Water body
LULC 1991	Built-up area	100.88	24.59	5.82	15.35	5.47	1.43	0.06	26.34	2.24
	Cultivated land	163.32	562.04	27.79	3.61	47.99	18.81	0.36	85.60	6.60
	Fallow land	14.25	6.43	3.31	1.61	3.97	0.68	0	3.96	0.63
	Industrial area	1.19	0.06	0.16	16.66	0.14	0.01	0	0.27	0.12
	Open-cast coal mining	5.44	3.37	1.84	0.04	6.94	0.47	0.01	2.24	0.98
	Protected forest	6.73	15.64	1.18	1.34	2.11	60.03	0	3.31	0.14
	Sand bar	0.54	6.25	0.47	0.03	0.38	0.11	7.93	0.64	1.41
	Sparse vegetation	131.02	54.29	10.64	12.10	17.38	3.76	0.04	76.68	3.42
	Water body	1.22	1.72	0.67	0.92	0.87	0.23	1.42	2.37	14.38

Source: Computed by the authors based on images analysis

Table 7.4 NDVI of Paschim Bardhaman for 1991 and 2021

	NDVI 1991			NDVI 2021		
Class	NDVI value	Area km^2	Area %	NDVI value	Area km^2	Area %
Very low	−0.416 −0.0539	40.1121	2.481	−0.231–0.071	140.027	8.661
Low	−0538–0.0794	614.884	38.031	0.0715–0.137	644.896	39.887
Medium	0.0795–0.171	767.298	47.458	0.137–0.200	635.972	39.335
High	0.172–0.656	194.509	12.030	0.200–0.497	190.168	11.762

Source: Computed by the authors based on images analysis

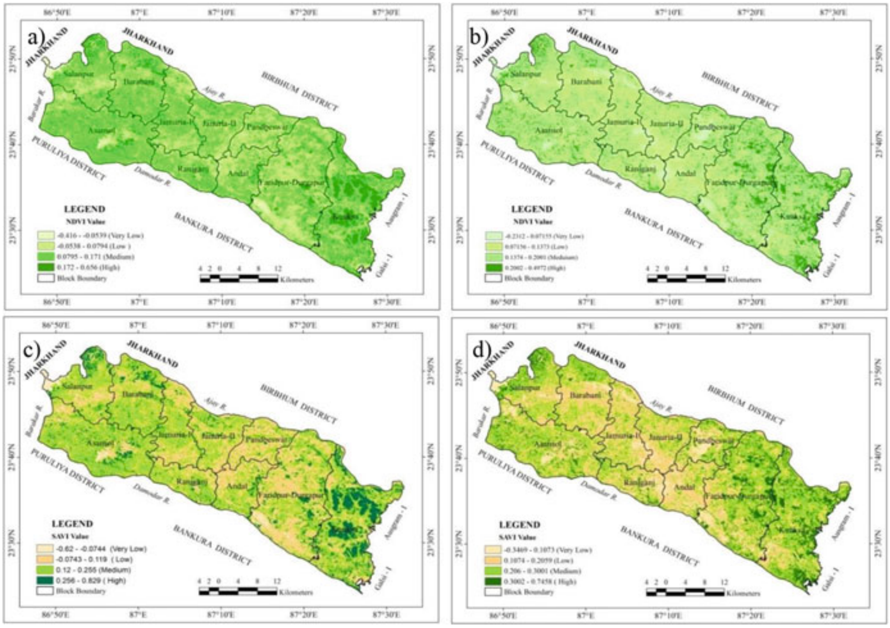

Fig. 7.5 Normalized difference vegetation index (**a**) 1991, (**b**) 2021; soil-adjusted vegetation index (**c**) 1991, (**d**) 2021

Table 7.5 NDVI for Asansol Municipal Corporation for 1991 and 2021

NDVI 1991				NDVI 2021		
Class	NDVI value	Area in sq. km	Area (%)	NDVI value	Area sq. km	Area (%)
Very low	−0.3962–0.009545	16.8444	5.10	−0.1188–0.066	22.1796	6.71
Low	−0.009544–0.06779	69.606	21.07	0.06694–0.1203	86.2074	26.09
Medium	0.0678–0.1193	138.537	41.93	0.1204–0.1621	138.857	42.03
High	0.1194–0.193	88.704	26.85	0.1622–0.2179	66.3813	20.09
Very high	0.1931–0.5429	16.8768	5.11	0.218–0.4733	16.7454	5.07

Source: Calculated by authors based on satellite image analysis

Table 7.6 NDVI of Durgapur Municipal Corporation 1991 and 2021

NDVI 1991				NDVI 2021		
Class	NDVI value	Area km	Area in %	NDVI value	Area km	Area in %
Very low	−0.333 to −0.0301	13.1283	8.616	0.115–0.072	14.3028	9.387
Low	−0.03–0.0501	43.6626	28.655	0.0721–0.127	47.3062	31.047
Medium	0.0502–0.113	57.0519	37.443	0.128–0.173	55.4183	36.371
High	0.114–0.2	30.5721	20.064	0.174–0.237	29.3895	19.288
Very high	0.201–0.556	7.956	5.221	0.238–0.468	5.9397	3.898

Source: Calculated by authors based on the satellite image

Table 7.7 SAVI of Paschim Bardhaman for 1991 and 2021

	SAVI 1991			SAVI 2021		
Class	SAVI value	Area (sq. km)	Area (%)	SAVI value	Area (sq. km)	Area (%)
Very low	−0.62 to −0.0744	19.3581	1.200	−0.3469–0.1073	112.609	6.980
Low	−0.0743–0.119	303.283	18.800	0.1074–0.2059	640.929	39.730
Medium	0.12–0.255	1027.64	63.702	0.206–0.3001	661.305	40.993
High	0.256–0.829	262.916	16.298	0.3002–0.7458	198.356	12.296

Source: Computed by authors based on image analysis

7.4.4 SAVI of the Study Area

Where vegetative cover is below average, due to the dominance of Soil brightness, Soil-adjusted vegetation index (SAVI) is used to rectify the shortcomings of the normalized difference vegetation index (NDVI). SAVI, a subject of Landsat surface inference derived, is an outcome of a calculative ratio between the red and NIR values with a soil brightness correction factor (L) associated with 0.5 to house most land cover types (USGS 2020). $L = 0$ means dense vegetation cover, whereas $L = 1$ means no vegetation cover. In common parlance, in the time of deriving SAVI, L is considered as 0.5 (Gilabert et al. 2002). NDVI and SAVI are more or less the same indices, and in the case of the SAVI, only a constant value of "L" is added to the denominator of the NDVI equation, and a multiplication factor $(1 + L)$ is needed in SAVI to maintain the bounded value (i.e., −1 to 1) of NDVI (Huete 1988). In the present study, ground verification reveals the presence of bare ground which helps determine the L factor as 0.5 for the calculation of SAVI. SAVI of the study area both for 1991 and 2021 reveals a noticeable change of vegetation cover. The derived SAVI for the study has been categorized into four groups (Table 7.7). It is depicted from the calculated SAVI that the proportion of high and medium values rapidly decreased from 1991 to 2021. Table 7.7 reveals that the area with high and medium SAVI decreased from 16.29 to 12.29% and 63.70 to 40.99% between the said

Table 7.8 SAVI of Asansol Municipal Corporation for 1991 and 2021

SAVI 1991				SAVI 2021		
Class	SAVI value	Area sq. km	Area (%)	SAVI value	Area sq. km	Area (%)
Very low	−0.5888 to −0.01813	16.659	5.011671	−0.1782–0.1004	22.1832	6.673564
Low	−0.01812–0.1026	75.3543	22.66949	0.1005–0.1805	86.211	25.9356
Medium	0.1027–0.1794	137.159	41.26273	0.1806–0.2432	138.856	41.77325
High	0.1795–0.2892	86.7789	26.10645	0.2433–0.3268	66.375	19.96817
Very high	0.2893–0.8104	16.4529	4.949668	0.3269–0.7099	16.7454	5.037663

Table 7.9 SAVI of Durgapur Municipal Corporation 1991 and 2021

SAVI 1991				SAVI 2021		
Class	SAVI value	Area km	Area in %	SAVI value	Area km	Area in %
Very low	−0.495 to −0.0428	13.3578	8.767	−0.173–0.108	14.3037	9.387
Low	−0.0427–0.0714	41.5098	27.245	0.109–0.19	43.308	31.047
Medium	0.0715–0.165	57.0132	37.420	0.191–0.259	56.4165	36.371
High	0.166–0.295	31.6386	20.766	0.26–0.355	29.3886	19.288
Very high	0.296–0.829	8.8371	5.221	0.356–0.701	5.354	3.514

Source: Computed by authors based on image analysis

periods, respectively. The rapid decrease of high and medium SAVI and increase of low and very low SAVI with the passes of time witness the phenomena of deforestation and land use change in the study area (Tables 7.8 and 7.9).

Considering the SAVI of Asansol Municipal Corporation (AMC), it is depicted that very high SAVI value remains almost stable, but the high SAVI value recorded remarkable negative change over the period (Table 7.8). The statistics of SAVI of AMC also authenticate the statistics of NDVI for the same area. Both in the years 1991 and 2021, about 30% of the AMC area recorded negative SAVI which reveals the presence of other than vegetation cover in the area. On the other hand, in Durgapur Municipal Corporation, negative growth was also noticed in the case of SAVI like NDVI. The vegetation pattern here changes over time. Very high vegetation has decreased to approximately 3% from 1991 to 2021 (Table 7.9). In the same way, it is noticed that very low and low vegetation cover have increased by about approximately 1% and 4%, respectively.

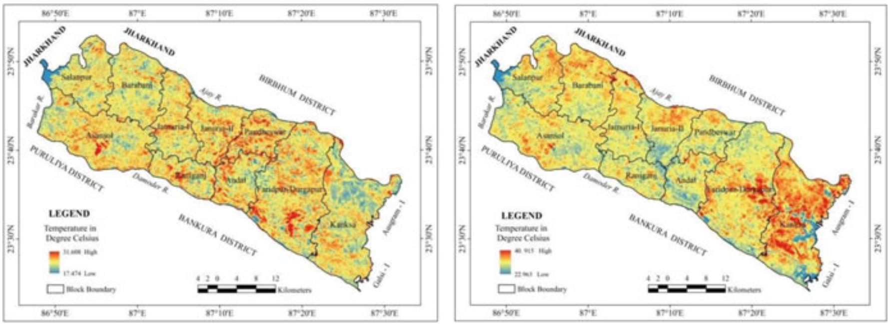

Fig. 7.6 Land surface temperature in study area (**a**) 1991, (**b**) 2021

7.4.5 Spatiotemporally in LST

The spatial distribution of the temperature in the district of Paschim Bardhaman in the year 1991 varies from 31.640 to 17.474 °C. The lowest concentrations of temperature are found in the eastern, western, and northwestern sides of the district both for the years 1991 and 2021 (Fig. 7.6a, b). At the same time, maximum temperature is located in the southern and middle portions of the study area, especially in the municipality area. The temporal variation of overall temperature in the study area is remarkable; both the highest and lowest temperature recorded a positive increase over time (Fig. 7.6a, b). The concentration of the highest and lowest temperature of the study area can be correlated with the presence and absence of high and low concentrations of vegetation cover as derived from the calculation of NDVI and SAVI of the same area.

7.4.6 Comparison of LST Between AMC and DMC

The difference of change in LST between AMC and DMC has also been observed in this study. These two areas have been selected because those two areas underwent the highest rate of urbanization among all the areas of Paschim Burdwan and are susceptible to a high rate of deforestation and various types of pollution which makes them have altered LSTs. The highest temperature of the area increases to 40.915 from 31.640 °C, and the lowest temperature increases from 17.474 to 22.963 °C from 1991 to 2021.

In 2021, this region has recorded a huge increase in temperature which varies from 40.91 to 22.96 °C. Considering the statistics of AMC and DMC, it is observed that like the whole study area, both have recorded a noticeable increase in temperature over the period. The average highest temperature in AMC and DMC increased from 31.64 to 39.62 °C between the decades of 1991 and 2021. AMC has recorded

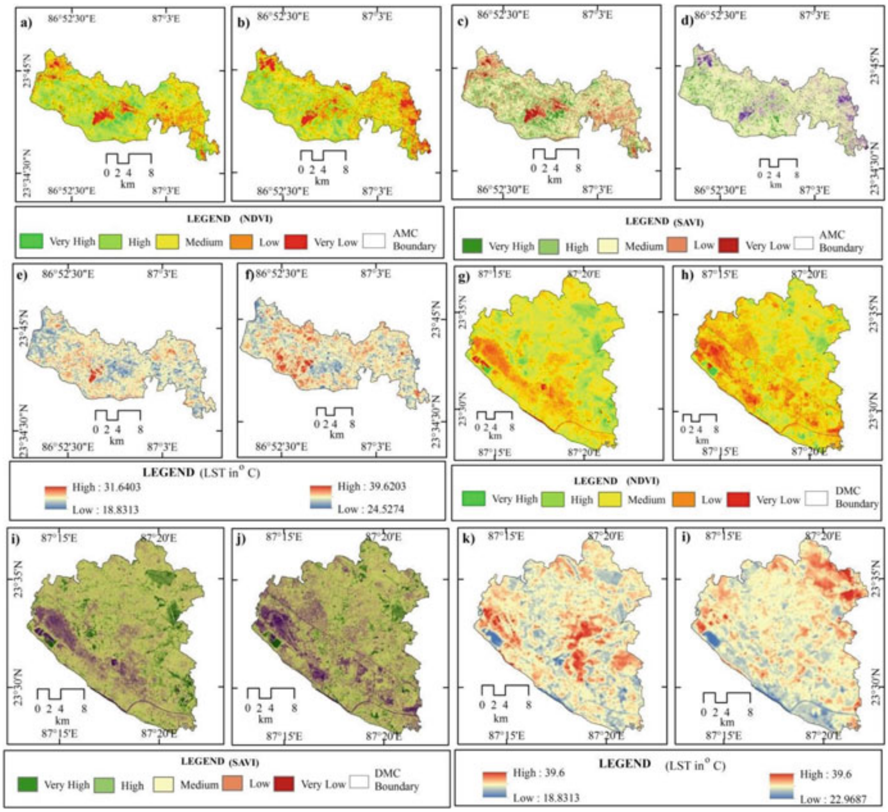

Fig. 7.7 (**a**) NDVI of 1991, AMC. (**b**) NDVI of 2021, AMC. (**c**) SAVI of 1991, AMC. (**d**) SAVI of 2021, AMC. (**e**) LST of 1991, AMC. (**f**) LST of 2021, AMC. (**g**) NDVI of 1991, DMC. (**h**) NDVI of 2021, DMC. (**i**) SAVI of 1991, DMC. (**j**) SAVI of 2021, DMC. (**k**) LST of 1991, DMC. (**l**) LST of 2021, DMC 2021

the increase of average lowest temperature from 18.831 to 24.527 °C, whereas DMC recorded a slightly minimum increase of average lowest temperature from 18.831 to 22.96 °C in the said period (Fig. 7.7c, d). From the discussion, the overall huge increase of average highest and lowest temperature has been noticed. The average increase of temperature can further be correlated with the rapid expansion of built-up area, coal mine area, as well as lowing of forest cover and cultivated area. At the same time, the pace of temperature increase may be considered as the warning for the future development of the area.

7.4.7 Urban Green Space of AMC and DMC

Urban green spaces are generally those public or private open spaces clothed with scattered green plants in urban areas which offer the blessings of multifunctional benefits directly or indirectly to the city dwellers and consumers (Manlun 2003). Urban green space helps improve the quality of life in an urban ecosystem, particularly high densely populated countries like India (Chaudhry 2016).

Urban green spaces can also help maintain the water quality, reducing stormwater runoff, reducing the heat island effect and sequestering carbon dioxide reducing air pollution. So, green spaces in an urban the area is very significant from an environmental point of view. WHO and FAO recommended norms for 9 square meters of green open space per person in urban areas (Dhali et al., 2019; Kuchelmeister 2000); but many Indian cities except Gandhinagar and Chandigarh already fall short of per capita green space availability. In India, the rapid expansion of urban areas and the increase of urban population caused lowering of green space. At present, the concept of urban green space can be gained and managed by different models and remote sensing techniques. Different researchers are using different indices such as NDVI, LAI (Leaf Area Index), LST (Land Surface Temperature), and LSE (Land Surface Emissivity) for understanding the condition of the urban green spaces as well as different factors that would be related to urban green space. For the favorable management of urban green space landscape ecological approach, integrated approach, urban forest effect model, etc. are used. In common parlance, every industrial town is highly urbanized, suffering for the space in those towns which caused the removal of urban green space in those areas. A comparative analysis of the two images shows that in both Asansol and Durgapur subdivisions, urban green spaces are declining (Fig. 7.8). At the core region of the two cities, the presence of trees is significantly observed very low. The study brings out that the green space of

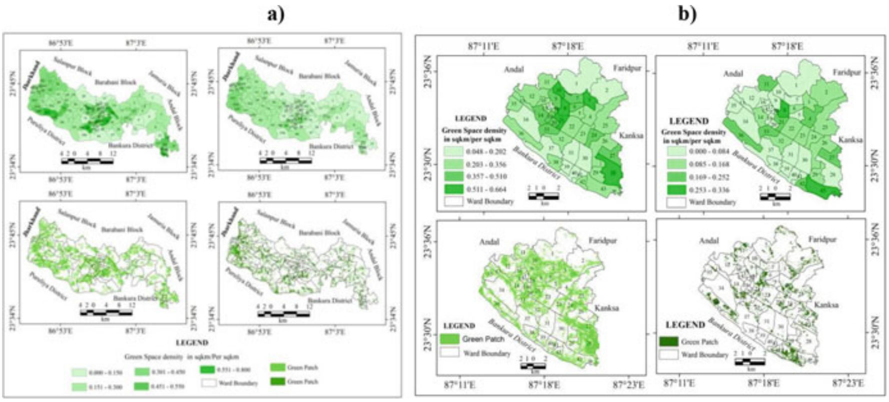

Fig. 7.8 Urban green space of (**a**) AMC and (**b**) DMC

the cities is transformed into a buildup area over time. The main reasons behind these changes in urban green space in the Asansol-Durgapur region have been identified firstly as the rapid rate of urbanization secondly rapid economic development, and thirdly huge population pressure. At present, the administration of these cities must give prior importance to increasing the green cover of these cities to recover the living environment as well as to stop further degradation of the same.

7.4.8 Correlation of LST with Urban Green Space Density and NDVI

This study has been measuring the relation between the urban green space density of Asansol Municipal Corporation (AMC) and Durgapur Municipal Corporation (DMC) with LST and NDVI. The relation between urban green space density and LST is negative for both the years 1991 ($R^2 = 0.027$) and 2021 ($R^2 = 0.029$), respectively (Fig. 7.9a, b); the result also shows the negative relationship between NDVI and LST. Whereas the relation between NDVI and LST in AMC is also negative for 1991 ($R^2 = 0.1453$) and 2021 ($R^2 = 0.1582$), respectively (Fig. 7.9c, d). Furthermore, in the case of DMC, the relation between urban green space density and LST is also negative both in the years 1991 ($R^2 = 0.0668$ and) and 2021 ($R^2 = 0.0251$), respectively (Fig. 7.9a, b). From the above discussion, it is derived that the LST is inversely proportional to urban green space. Similarly, in these corporations, the urban green space is declining gradually leading to an increase in LST.

Deforestation in the Paschim Bardhaman districts is mainly triggered by a few anthropogenic activities. Expansions of urban and industrial areas are the most responsible anthropogenic factors of forest cover reduction which have been discussed in the following sections.

7.4.9 Growth of Urban Areas of Paschim Bardhaman and Loss of Urban Green Space

The pace of growth of Asansol and Durgapur led to the formation of a second metropolis within the state. Industrial and urban growth are mainly focused on these two centers. These centers are undergoing a rapid transformation of intermediate rural hinterland into urban. The swift urban growth of the Asansol-Kulti-Jamuria region is the result of its geographical location, i.e., on the eastern bank of river Barakar and the northern bank of river Damodar. Besides, the G.T. road, as well as the Durgapur-Dhanbad railway linkage also adds extra momentum to the growth of this region (ADDA 2010). More than 77% of its total population is urban comprising about 2.4 million. About 88% of the erstwhile Bardhhaman district's urban

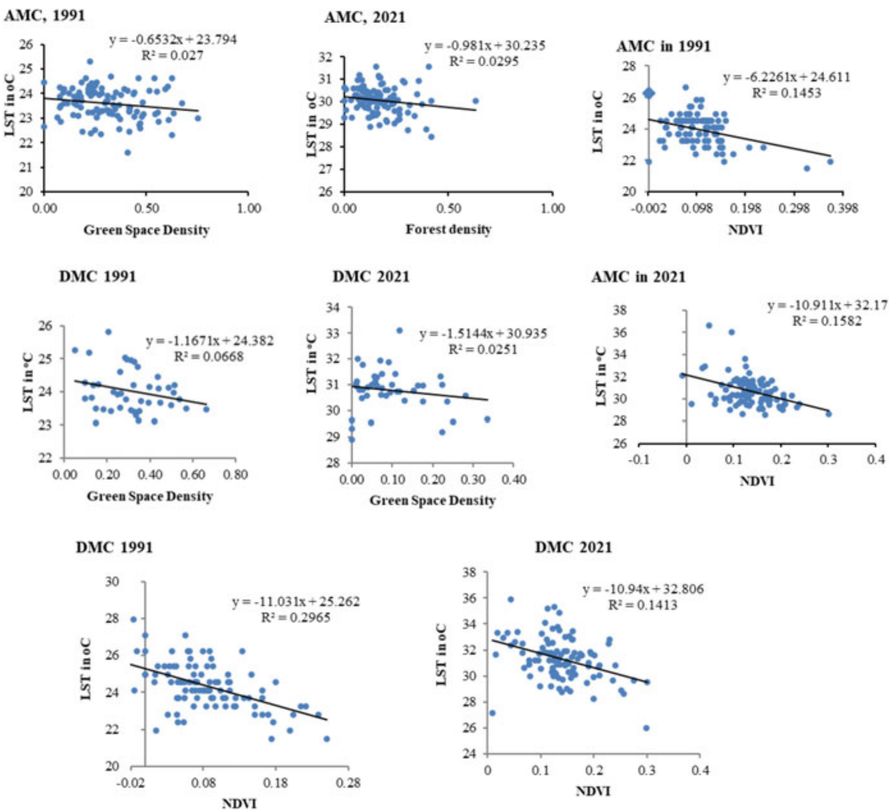

Fig. 7.9 Correlation between green density and LST DMC and AMC (**a**) 1991, (**b**) 2021; correlation between NDVI and LST (**c**) 1991, (**d**) 2021

population resides in the ADPA (Asansol Durgapur Planning Area) according to the 2011 census (Chaudhuri 2001).

A remarkable expansion of settlement areas has been observed in the Paschim Bardhaman district. The expansion of built-up area from 1991 to 2021 has been recorded from 187.58 to 424.45 km^2, and presently it covers ~26.58% of the total land area of Paschim Bardhaman district. Remarkable deforestation is recorded in the Asansol, Raniganj, Andal, Jamuria-I, and Durgapur C.D. block. Moreover, AMC and DMC also suffer from the lowering of green space. Asansol Municipal Corporation (AMC) is the 2nd largest urban center of West Bengal after Kolkata. AMC is formed by the merging of erstwhile four municipalities, namely, Asansol, Jamuria, Kulti, and Raniganj (MSME 2019) have recorded the tremendous growth of the built-up area and the lowering of the green cover area. DMC emerged as an industrial town during the second 5-year plan, in the time of development of basic industrial development of this country after getting freedom from the colonial government and due to rapid industrialization, the same problem of AMC also found here.

7.4.10 Industrial Expansion and Reduction of Forest Cover

The district is renowned for its rich mineral base coupled with power sources. The traditional industrial base in this district is principally founded by the supply of huge indigenous coal resources. The rapid development of industries has been experienced for the iron and steel industry, but recently engineering, coal-based chemicals, and fertilizers are also found emerging at significant number. The main industrial areas of this district are primarily located in AMC and DMC. A large reservoir of coal and consequential extraction activities, favorable environment, and proximity to ores have influenced large iron and steel industries to set up in this region. Besides, other extraction-based industries like heavy engineering works, chemical industries, distilleries, refractories, etc. have been set up here as well. Some of the most noted are the IISCO plant in Kulti and Burnpur, Chittaranjan locomotive factory, Hindustan cables factory in Chittaranjan, and Sen-Raleigh cycle manufacturing unit, etc. (Basu 2018). However, over time, decline in the use of production technology has led to the collapse of many significant manufacturing units. In recent times, both the public and private sectors helped in strengthening the industrial climate by making fresh investments. IISCO Burnpur has experienced a remarkable transformation after its merger with Steel Authority of India Limited (SAIL). Apart from these several, medium small-scale industries like private iron and steel plants, coal-based plants are being set up here as well (ADDA 2010).

The rapid development of the large, medium, and small-scale industries requires more land acquisition, availability of raw materials, infrastructure, e.g., roads and railway networks, etc. Therefore, the conversion of forest land into other land use especially into the industrial area has become an important environmental issue (Rahaman et al., 2019; Ghebrezgabher et al. 2014). Moreover, deforestation as a result of the rapid expansion of coal mining areas in this area has become another significant anthropogenic activity causing the vulnerability of landscape ecology and degradation of forest resources (Dutta et al., 2017).

7.5 Recommendation and Policy Suggestions

There is no panacea for the lowering of the green space in the study area, but a holistic approach toward the same can minimize the problems to a great extent. As the study area is highly urbanized and industrialized, overpopulation is a major problem of the area. The expansion of the region in the fringe area in a planned way can reduce the problem of overpopulation which indirectly reduces the further lowering of green space. Besides, good governance can overshadow the lowering of green space. If diffident existing provisions and new provisions can be implemented to restrict the demolition of green cover in the area, it will automatically rejuvenate the previous glory of the urban space. Replanting of few parts of the area and replanting trees can act as a helpful measure for the same.

7.6 Conclusion

It appears from the above discussion that the gradual decrease of green space in these two major subdivisions directly affects the environment. Since Asansol and Durgapur are two important industrial zones, the level of pollution in these two areas is increasing at an alarming rate. This study also witnessed that urban green space has a direct impact on the temperature of the urban areas as greater urban density in association with lesser green density is the cause of greater land surface temperature (LST) and vice versa in Asansol, as well as Durgapur M. Corp. Urbanization, which is occurring all over the world, and developing countries evidenced a great surge in the urban population. Along with the development of the city, the planner should increase the urban green space so that it can protect the dwellers from various environmental issues. Therefore, this kind of research is much more significant especially from an environmental point of view. For future sustenance of urbanites, these two municipal corporations have to conserve the urban green space and increase the urban green space through tree plantation, social forestry, urban forestry, etc. Though utmost dedication has been given to weed out this work, this work is not free from lacuna. The pandemic situation caused by the COVID-19 virus hindrance us from getting present ground verification of the study area. The present work can be concluded by emphasizing the need for continuous monitoring of forest resources of the study area to ensure a sustainable environment for society. Therefore, planning and deep research on urban green space for these industrial urban areas are very essential.

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Chapter 8
Floristic Composition and Inventorization of Forest Resources in Some Selected Forest Areas of Paschim Bardhaman District, West Bengal, India

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Abstract Forests are the treed-dominated Earth's terrestrial ecosystem. Human culture and forests both have positive and negative effects on one another. The key focus of this study is to analyze the plant phytosociology and diversity of two selected forest areas (Pardaha and Rupganj) of Paschim Bardhaman district, West Bengal, India. The forest area is mainly affected by massive population growth, land use shift in irrigated areas, and rapid urbanization in agricultural land, in recent decades. The floristic composition and phytoclimatic attributes are certainly the most important forest ecology research areas for the conservation, regeneration, and protection of the forest. Floristic study of the two forest patches (Pardaha and Rupganj) has shown that they have collectively accommodated as many as 101 different species under 89 different genera. The generic coefficient value, which is about 88 percent, reflects the large range of biodiversity within the studied patches. *Azadirachta indica*, *Cassia siamea*, *Shorea robusta*, *Cynodon dactylon*, *Clerodendrum viscosum*, and *Holarrhena antidysenterica* can be considered as very important plant species in terms of IVI, and these species can be utilized for effective forest management. This chapter revealed the high resource potentiality of the studied forest which can contribute to the economy and livelihood of forest

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dwellers. It also provides an insight into various forest-based resources of the concerned region. The results reflect a tentative effort toward formulating eco-floristic strategies for increasing and maintaining the forest patches addressed.

Keywords Forest · Phytosociology · Diversity · Generic coefficient · Livelihood

8.1 Introduction

Forests are vast reservoirs of species and habitat (Noble and Dirzo 1997). Human activities on forest lands will have a significant impact on local, regional, and global biodiversity, along with natural ecosystem viability and functioning (Kimmins 1997). Several forests are severely impacted by human activity, which necessitates management intervention to ensure total biodiversity, production, and long-term sustainability (Kumar et al. 2002). To analyze the diversity and resources of these forests, it is necessary to understand species diversity and population structure (Kumar et al. 2006). Most fundamental investigations in tropical natural environments, such as anticipating trends of species richness or understanding species distributions, need a floristic inventory (Phillips et al. 2003). In many places of the world, several research on floristic diversity have been performed. A great deal of research is focused on inventory (Sagar et al. 2003; Padalia et al. 2004; Appolinario et al. 2005). Apart from inventory, floristic assessment is also used to investigate the impact of disturbance on regeneration (Kennard et al. 2002), as well as to track changes in the environment (Sukumar et al. 1992). As a result, it's no surprise that a variety of researchers all over the world undertake floristic studies at various levels, and a range of sampling and measuring approaches has been employed. Forests play a vital role in the lives of forest inhabitants, contributing to their social and economic well-being, as well as providing adequate livelihood alternatives and ecological services. Forests are an important part of nature that provide a variety of ecosystem services in both physical and intangible forms, including hardwood, fuelwood, firewood, medicinal and aroma plants, and so on. Besides food and nutritional security, rural and tribal peoples gather these items to meet their basic requirements, which play a vital role in socioeconomic upliftment and livelihood security. Poor farmers' and indigenous peoples' livelihoods, on the other hand, are intertwined with a variety of forest products, which they sell on the market (Mukul et al. 2016). Several scholars have calculated the proportion of tribal reliance on forests in developing nations. According to Belcher et al. (2005), household income created by forest resources is used for various consumptive purposes across the Asian continent. For instance, 72.5 percent of families gathered forest-based timber, and 82.5 percent collected fuelwood for domestic use. Similarly, forest-dependent tribal peoples in Nepal receive around 22 percent of total yearly household income from forest-based resources (Baloch et al. 2015). In Jharkhand, firewood alone generated 50% of total family yearly revenue (Belcher et al. 2005). Furthermore, many works have reported a significant role of different forest resources in improving the subsistence of rural and tribal inhabitants (Akanni and State 2013; Angelsen et al.

2014; Soe and Yeo-Chang 2019), and it is not limited only to livelihood creation but also retains species richness and diversity, improves conservation efforts, and intensifies ecosystem services (Areendran et al., 2020) such as soil enrichment and climate security through carbon sequestration (Babbar et al., 2021; Jhariya and Singh 2020). Therefore, it enhances total soil-food-climate resilience, ensuring sustainability and environmental equilibrium (Ndangalasi et al. 2007; Chidumayo and Gumbo 2013; Solomon 2016; Dao and Hölscher 2018). As a consequence, these are some potential instances of forest contributions to forest inhabitants' livelihoods. So, we can't deny the multifarious role of forests in livelihood generation; however, we can't achieve the goal of maximum and quality production forest for livelihood and sustainable development without emphasizing on sustainable utilization of forest products. In this context, sustainable forest management (SFM) becomes a good strategy that increases productivity as well as forest health (Yadav et al., 2022).

There are little or no research studies to address the floristic picture of forests in the Durgapur forest region (Bhattacharya and Mukherjee 2006; Bouri and Mukherjee 2011). This chapter aims to demonstrate the composition of flora and species diversity pattern in two different patches of the Durgapur Forest Range, as well as analyze the life form structure to gain a better understanding of the concurrent biological spectrum, which will aid in controlling the forest structure through revegetation and effective management strategy of the forest. Moreover, in this chapter, we also prepare an inventory of the different forest products extracted in the region. This study, the first of its type in the area, describes and analyses floristic composition as well as different non-timber uses of plants linked primarily with the lives of forest dwellers. Accurate documentation of the forest's plant resources is required to ensure the conservation status of the studied forest and to enable sustainable administration (Dutta et al., 2021). In this regard, understanding the floristic composition, structure, and natural regeneration of the investigated forest regions is essential. Ecological data acquired in this respect would be beneficial for implementing sustainable forest management practices.

8.2 Materials and Methods

8.2.1 Study Area

The study was undertaken in Pardaha and Rupganj forest located in Paschim Burdwan, West Bengal, India. The Pardaha forest is located between 23°32′49.29"N latitude and 87°19′23.34″E longitude (Fig. 8.1). The Rupganj Forest is located between 23°32′1.37" N and 87°23′13.16″E. The nearest town to these forests is Durgapur. This is a dry deciduous natural forest. The Rupganj forest is a North Peninsular Dry Sal Forest of Purba Durgapur which is half artificial and half natural. The climate of the Pardaha and Rupganj forest areas is tropical. The temperature ranges from 34 °C to 45 °C in the summer and 8 °C to 15 °C in the winter. Annual rainfall ranges from 120 to 150 cm. A red lateritic type of soil is present in the selected study area. Various types of anthropogenic activities were

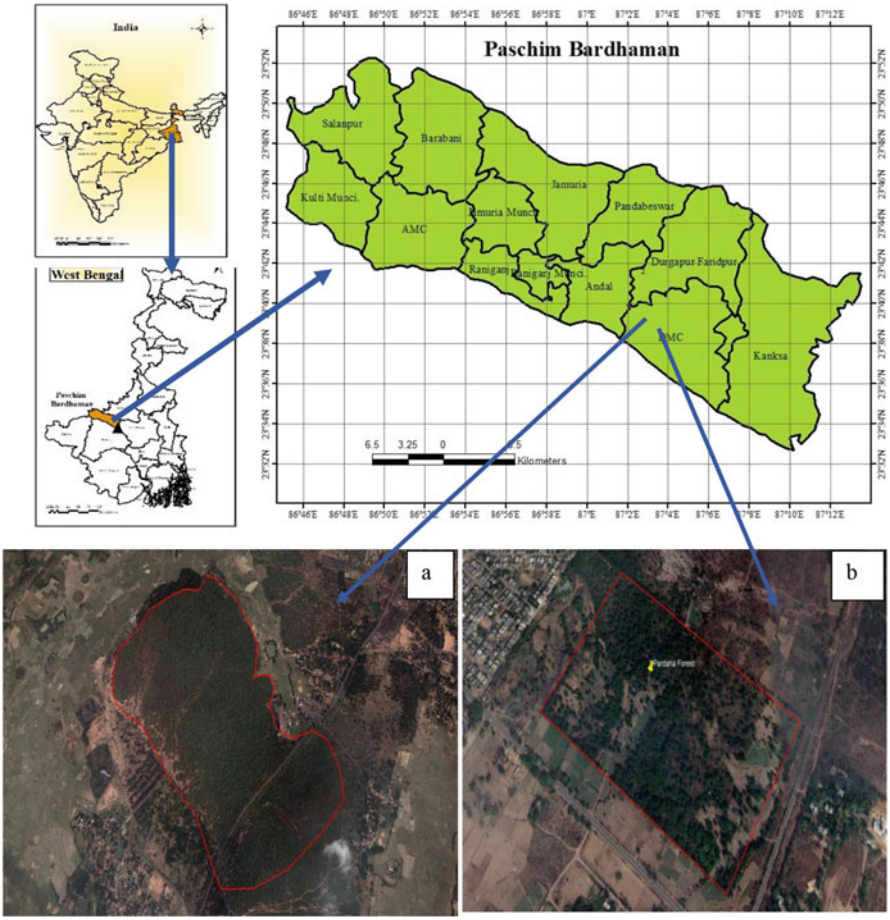

Fig. 8.1 Location of the Pardaha and Rupganj forest in the context of India, West Bengal and (**a**) Paschim Bardhaman District and a satellite imagery (Google Earth Pro) of the study area. (**b**) Rupganj forest, (**c**) Pardaha forest

performed in these forests such as fuelwood extraction and cattle grazing; a part of these forests is used as agricultural land, and the other part is also used as dumping areas.

8.2.2 Data Collection and Sampling

The inquiry was founded on primary data gathered over a 2 years' survey in the subject region. The quadrat technique was used to analyze the vegetation diversity for 2 years (2018–2020). Throughout the research period, a floristic survey was conducted to properly document and depict the plant species of the study sites. From

2018 to 2020, frequent field visits were made to the Pardaha and Rupganj forests. During the fieldwork, plant species were observed, some specimens were gathered, and pictures were taken (Fig. 8.2). Plant species were identified by Cook (1996) and Prain (1963).

For vegetation sampling, three locations representing diverse types of natural forests and plantations were chosen. To quantify distinct strata, 30 quadrats (1 × 1 m) were placed at each location. The size of the quadrat utilized in this investigation was determined using Misra's species-area curve technique (1968). Individual plants, herbs, and trees were counted in each quadrat. Whitford's index was used to establish the pattern of distribution (Tripathi et al. 1991; Jhariya et al. 2012).

8.3 Data Analysis

Phytosociological characters like relative density, relative frequency, relative abundance, and importance value index (IVI) were estimated for each layer of vegetation (tree, herb, and shrub) following the methods of Misra (1968). The abundance-to-frequency ratio was calculated to analyze the species distribution pattern (A/F) (Curtis and Cottam 1956). Different diversity indices such as Shannon Wiener diversity index (Shannon and Weaver 1963), Simpson's index of dominance (Simpson 1949), evenness (Pielou 1966), and species richness index (Marglef 1958) were estimated.

$$\text{Relative frequency (RF)} \frac{\text{frequency of each species}}{\text{total frequency}} \times 100$$

$$\text{Relative density (RD)} \frac{\text{density of each species}}{\text{total density}} \times 100$$

$$\text{Relative abundance (RA)} \frac{\text{abundance of each species}}{\text{total abundance}} \times 100$$

$$\text{Importance value index (IVI)} = \text{RF} + \text{RD} + \text{RA}$$

$$\text{Species Richness (SR)} = \frac{(S - I)}{\ln(N)}$$

where S is the number of species and N is the total number of individuals in the sample.

Shannon Wiener diversity index, (H′) has been calculated as:

$$H' = \sum Si = \text{pi} \ \ln pi$$

where pi represents the potential abundance of the ith species in the community.

Simpson's index of dominance, (CD) has been calculated as:

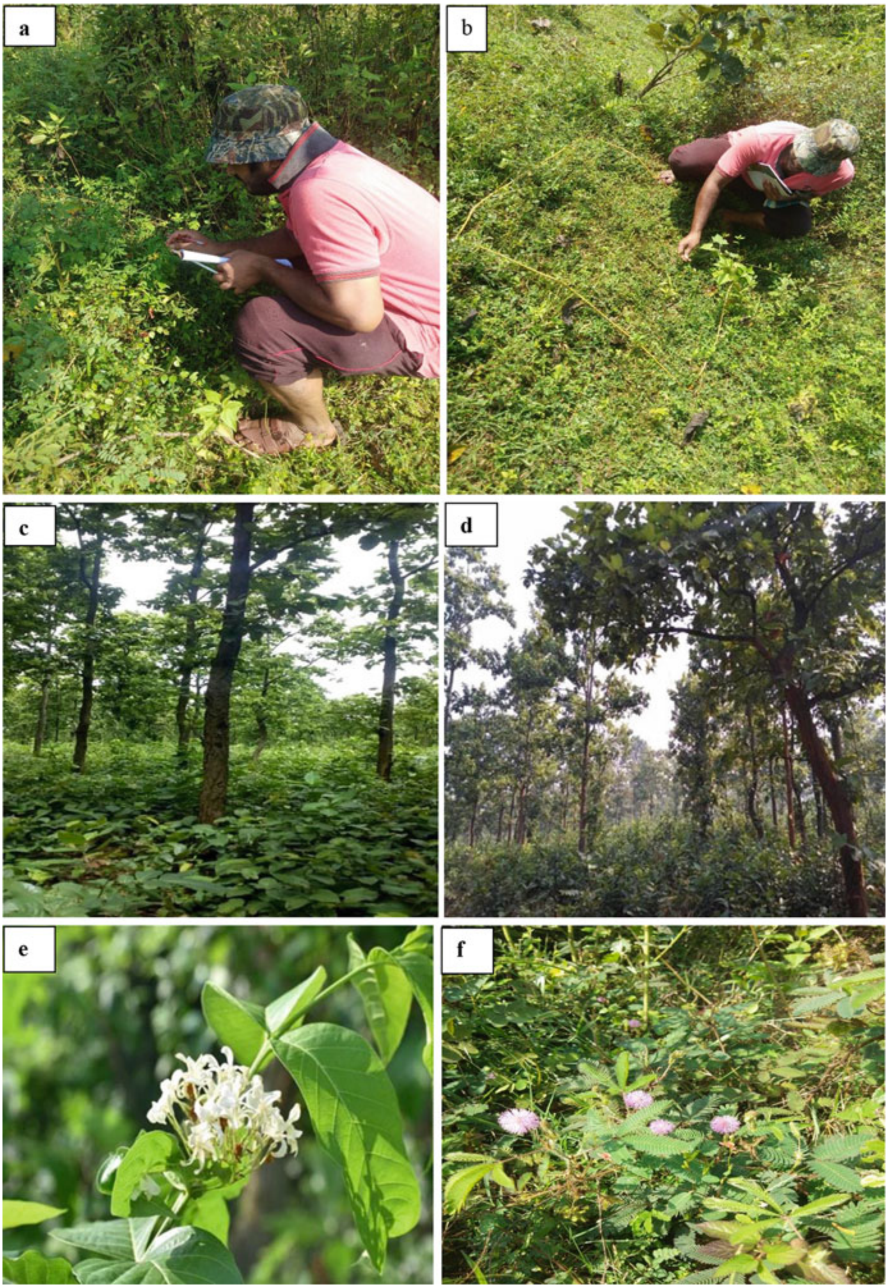

Fig. 8.2 Glimpses of the two studied forests and some plant species identified during the field study. (**a**) and (**b**) field study and sample collection, (**c**) Pardaha forest, (**d**) Rupganj forest, (**e**) *Holarrhena antidysenterica*, (**f**) *Mimosa pudica*, (**g**) *Synedrella nodiflora*, (**h**) *Tridax procumbens*, (**i**) *Euphorbia hirta*, (**j**) *Oldenlandia corymbosa,* (**k**) *Ruellia tuberosa,* (l) *Lantana camara*

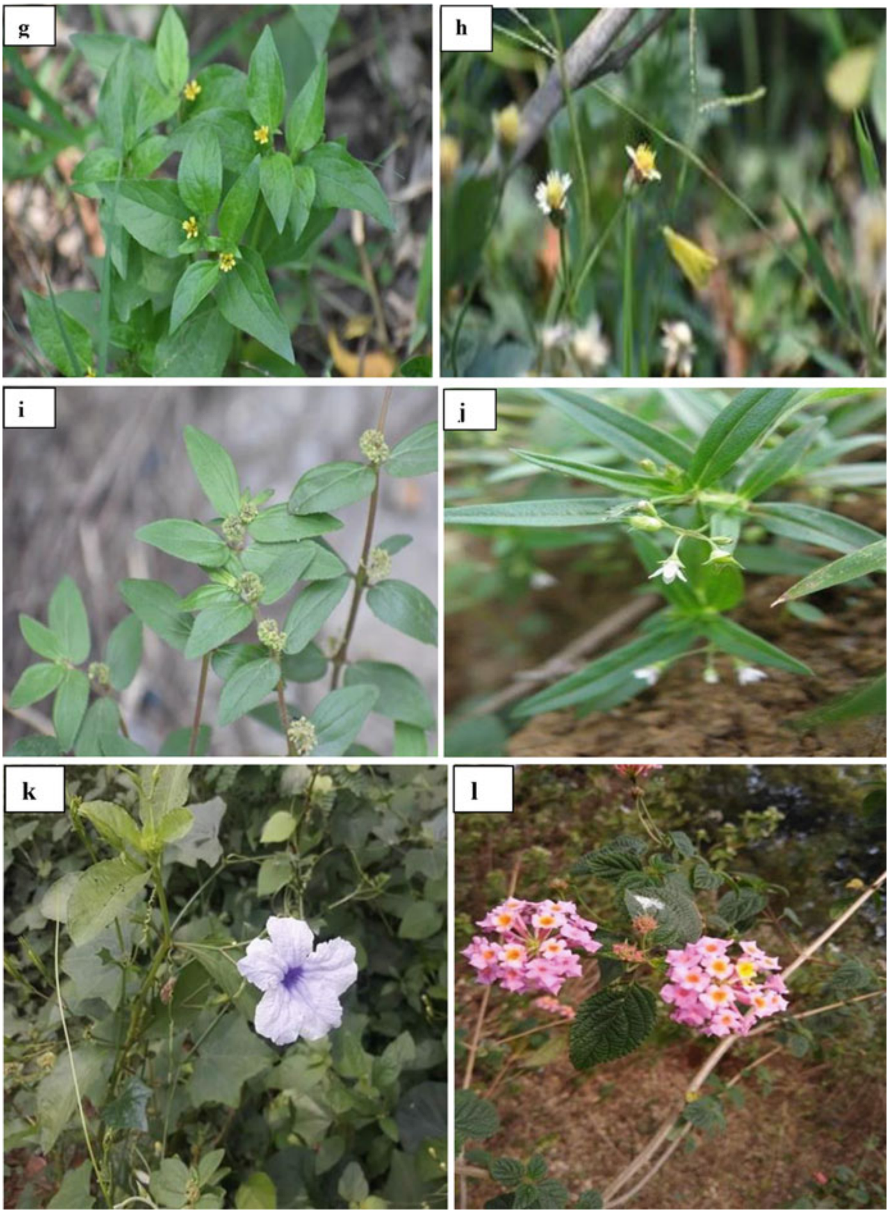

Fig. 8.2 (continued)

$$\mathrm{CD} = \sum Si = 1(Pi)^2$$

where Pi is the same as for the Shannon Wiener diversity index.

Evenness index (e), has been calculated as:

$$\mathrm{e} = {}^{H'}\!/_{\log S}$$

where H' is the number derived from the Shannon diversity index and S is the total number of species.

8.4 Result

A total of 92 species belonging to 81 genera and 51 families were revealed during the vegetation assessment of Pardaha forest (Table 8.1). Out of a total of 38 families in the study area, the dominant families were Fabaceae (10 species) and Asteraceae (10 species). 67 species belonging to 63 genera and 44 families were identified during the vegetation assessment of Rupganj Forest (Table 8.1). Out of a total of 44 families in the study area, the dominant families were Asteraceae (7 species) and Poaceae (5 species). Information on life span, life form, flowering, and fruiting time of plants were recorded (Table 8.2). Raunkiaer (1934) provided a comprehensive system of plant life form classification based on their adaptations for surviving the unfavorable season. It can be distinguishing to phanerophytes, chamaephytes, hemicryptophytes, cryptophytes, and therophytes. The comparison of the biological spectrum of the Pardaha forest is presented in the graph in Fig. 8.3. The vegetation of the study area showed the highest percentage of phanerophytes (40%); other groups of life forms in order of importance are therophytes (36%), chamaephytes (12%), hemicryptophytes (11%), and cryptophytes (1%) (Fig. 8.3). A summary of phyto-sociological data is summarized in Tables 8.3, 8.4, 8.5, 8.6, 8.7, and 8.8. In the Pardaha forest, *Cassia siamea* exhibits the highest IVI (68.94). In the Rupganj forest, *Shorea robusta* exhibits the highest relative density and IVI (44.49 and 96.76, respectively). The clumped type distribution pattern was observed in most of the plant species in the selected forest areas (>0.5).

Table 8.1 Enumeration of different layers of vegetation in Pardaha and Rupganj forest

Pardaha					Rupganj			
	Tree	Herb	Shrub	Total	Tree	Herb	Shrub	Total
Family	14	21	16	51	08	21	15	44
Genus	16	44	21	81	08	39	16	63
Species	19	49	24	92	09	41	17	67

Table 8.2 List of life spans, life forms, and flowering-fruiting times of plants occupying in Pardaha and Rupganj forest

Plant species	Life span	Life forms	Flowering and fruiting time
Abrus precatorius	Perennial	Phanerophyte	September–December
Abutilon indicum	Annual or perennial	Chamaephyte	January–April and September–December
Acacia auriculiformis	Perennial	Phanerophyte	January–February and August–December
Acalypha indica	Annual	Therophyte	June–October
Achyranthes aspera	Annual or perennial	Therophyte	January and November–December
Aegle marmelos	Perennial	Phanerophyte	May–August
Ageratum conyzoides	Annual	Therophyte	January–February and November–December
Albizia lebbeck	Perennial	Phanerophyte	January–March and October–December
Allophylus cobbe	Perennial	Phanerophyte	
Alstonia scholaris	Perennial	Phanerophyte	January and October–December
Alternanthera ficoidea	Perennial	Chamaephyte	January–December
Alysicarpus ovalifolium	Annual	Phanerophyte	June–August
Amaranthus spinosus	Perennial	Therophyte	January–December
Amaranthus viridis	Perennial	Therophyte	January–December
Andrographis paniculata	Annual	Therophyte	November–December
Anisomeles indica	Perennial	Therophyte	May–October
Argemone mexicana	Annual	Phanerophyte	January–February
Azadirachta indica	Perennial	Phanerophyte	March–July
Blumea lacera	Annual	Therophyte	January–March and November–December
Boerhavia diffusa	Perennial	Phanerophyte	June–September
Borassus flabellifer	Perennial	Phanerophyte	March–May
Calotropis procera	Perennial	Chamaephyte	January–December
Cassia fistula	Perennial	Phanerophyte	March–June
Cassia siamea	Annual	Therophyte	May–August
Cassia sophera	Perennial	Therophyte	October
Cassia tora	Annual	Therophyte	August–December
Chrysopogon aciculatus	Perennial	Chamaephyte	July–September
Cleome viscosa	Annual or perennial	Therophyte	June–October
Clerodendrum viscosum	Annual	Therophyte	July–October
Cocculus hirsutus	Perennial	Phanerophyte	July–October
	Perennial	Phanerophyte	

(continued)

Table 8.2 (continued)

Plant species	Life span	Life forms	Flowering and fruiting time
Combretum roxburghii			January–June and November–December
Crotalaria juncea	Annual	Therophyte	May–September
Crotalaria pallida	Annual or perennial	Therophyte	December
Croton bonplandianum	Perennial	Therophyte	January–December
Cynodon dactylon	Perennial	Hemicryptophyte	May–September
Cyperus esculentus	Annual or perennial	Hemicryptophyte	May–June
Cyperus rotundus	Perennial	Cryptophyte	January–December
Dalbergia sissoo	Perennial	Phanerophyte	January–December
Eclipta alba	Annual	Therophyte	January–December
Elephantopus scaber	Perennial	Therophyte	August–October
Eragrostis tenella	Annual	Hemicryptophyte	March–June
Eupatorium odoratum	Perennial	Chamaephyte	January–December
Euphorbia hirta	Perennial	Chamaephyte	September–December
Ficus hispida	Annual	Phanerophyte	
Ficus religiosa	Perennial	Phanerophyte	January–May and November–December
Gamochaeta coarctata	Annual	Therophyte	January–December
Gomphrena serrata	Perennial	Therophyte	January–December
Heliotropium indicum	Annual	Phanerophyte	January and November–December
Holarrhena antidysenterica	Perennial	Hemicryptophyte	February–June
Hybanthus enneaspermus	Perennial	Therophyte	October–December
Hyptis suaveolens	Annual	Therophyte	January and August–December
Ilex sp.	Perennial	Phanerophyte	February–March
Kyllinga nemoralis	Annual	Therophyte	February–June
Lantana camara	Annual or perennial	Phanerophyte	April–October
Lathyrus sativus	Annual or perennial	Phanerophyte	January–April and September–December
Leonotis viscosum	Annual or perennial	Therophyte	July–November
Ludwigia perennis	Perennial	Phanerophyte	June–December
Madhuca longifolia	Perennial	Phanerophyte	March–April
Mangifera indica	Perennial	Phanerophyte	February–July
Melochia corchorifolia	Annual	Hemicryptophyte	June–December
Mimosa himalayana	Perennial	Phanerophyte	February–July

(continued)

Table 8.2 (continued)

Plant species	Life span	Life forms	Flowering and fruiting time
Mimosa pudica	Perennial	Hemicryptophyte	September–December
Murraya koenigii	Perennial	Phanerophyte	January–March and November–December
Murraya paniculata	Perennial	Phanerophyte	June–October
Ocimum gratissimum	Annual	Chamaephyte	September–October
Oldenlandia corymbosa	Perennial	Hemicryptophyte	February–May
Oldenlandia herbacea	Annual or perennial	Hemicryptophyte	July–December
Parthenium hysterophorus	Perennial	Therophyte	August–October
Peristrophe bicalyculata	Perennial	Phanerophyte	March–December
Phoenix acaulis	Annual	Phanerophyte	January–December
Phoenix sylvestris	Perennial	Phanerophyte	January and May–December
Physalis minima	Annual	Therophyte	January and September–December
Polyalthia longifolia	Perennial	Phanerophyte	April–June
Portulaca oleracea	Annual	Hemicryptophyte	September–December
Prunus laurocerasus	Perennial	Phanerophyte	April–May
Ricinus communis	Perennial	Therophyte	August–November
Ruellia tuberosa	Perennial	Therophyte	April–June
Saccharum ravennae	Perennial	Hemicryptophyte	September–December
Scoparia dulcis	Annual or perennial	Therophyte	September–December
Sesbania cannabina	Annual or perennial	Phanerophyte	April–September
Setaria viridis	Annual	Hemicryptophyte	January–December
Shorea robusta	Perennial	Therophyte	April–May
Sida cordifolia	Annual or perennial	Therophyte	October–December
Sida longifolia	Annual or perennial	Therophyte	October–December
Sida rhombifolia	Annual or perennial	Therophyte	October–December
Solanum nigrum	Annual	Chamaephyte	July–September
Solanum xanthocarpum	Annual	Chamaephyte	July–September
Sonchus oleraceus	Annual	Chamaephyte	July–September
Synedrella nodiflora	Annual or perennial	Therophyte	February–June
Syzygium cumini	Perennial	Phanerophyte	February–June
Tamarindus indica	Perennial	Phanerophyte	June–September
Tectona grandis	Perennial	Phanerophyte	June–September

(continued)

Table 8.2 (continued)

Plant species	Life span	Life forms	Flowering and fruiting time
Tephrosia purpurea	Annual or perennial	Chamaephyte	April–May
Terminalia arjuna	Perennial	Phanerophyte	July–September
Tridax procumbens	Perennial	Therophyte	August
Triumfetta rhomboidea	Perennial	Therophyte	June–August
Urena lobata	Perennial	Chamaephyte	June–August
Ziziphus mauritiana	Perennial	Phanerophyte	April–October
Ziziphus oenoplia	Perennial	Phanerophyte	April–October

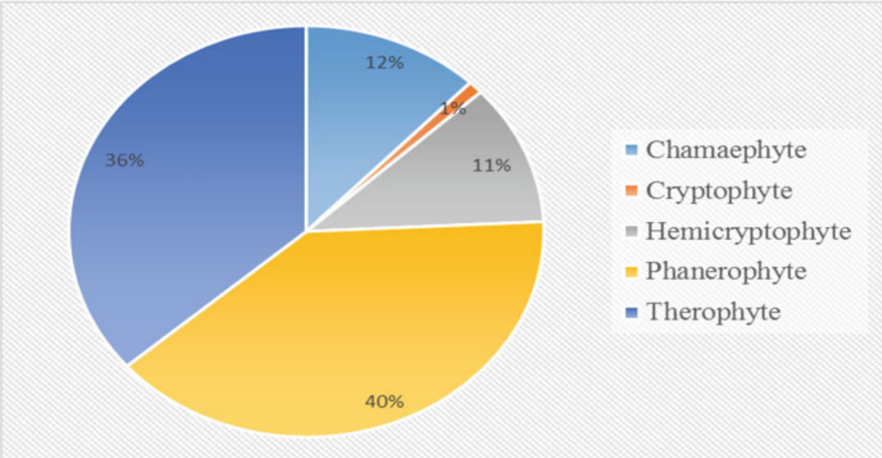

Fig. 8.3 Graphical representation of different life forms of the plants available in Pardaha and Rupganj forest

There was a variation among tree, herb, and shrub species as per the Shannon-Weaver diversity index (Table 8.9). In both research areas, herb species have a higher diversity than other forms of vegetation. The Simpson Dominance Index, or concentration of dominance, shows variance among the vegetation strata. In both the forests, the Evenness index and Margalef index for species richness reveal heterogeneity among distinct vegetation strata. The highest species richness and heterogeneity were observed for the herb layer. The plant species in these two studied forests produce flowers and fruits around the year. Most of the species' flowering and fruiting time is between July and October. The selected forest of this study comprised a large number of economically important plants and used for various purposes such as medicine, food, timber, and ornamental plants (Table 8.10)

Table 8.3 Phytosociological analysis of tree species in Pardaha forest

Sl. no.	Species	Family	RD	RA	RF	A/F	IVI
1	*Acacia auriculiformis*	Mimosaceae	6.67	5.49	9.17	0.05	21.33
2	*Aegle marmelos*	Rutaceae	2.92	4.00	5.50	0.06	12.42
3	*Albizia lebbeck*	Mimosaceae	1.25	3.43	2.75	0.1	7.43
4	*Alstonia scholaris*	Apocynaceae	2.5	5.15	3.67	0.11	11.32
5	*Azadirachta indica*	Meliaceae	34.17	12.79	20.18	0.05	67.14
6	*Borassus flabellifer*	Arecaceae	0.83	3.43	1.83	0.15	6.09
7	*Cassia fistula*	Fabaceae	1.25	5.15	1.83	0.23	8.23
8	*Cassia siamea*	Fabaceae	32.5	8.92	27.52	0.03	68.94
9	*Dalbergia sissoo*	Papilionaceae	3.75	7.72	3.67	0.17	15.14
10	*Ficus hispida*	Moraceae	1.67	4.57	2.75	0.13	8.99
11	*Ficus religiosa*	Moraceae	0.42	3.43	0.92	0.3	4.76
12	*Madhuca longifolia*	Sapotaceae	0.42	3.43	0.92	0.3	4.76
13	*Mangifera indica*	Anacardiaceae	1.67	4.57	2.75	0.13	8.99
14	*Phoenix acaulis*	Arecaceae	1.67	4.57	2.75	0.13	8.99
15	*Polyalthia longifolia*	Annonaceae	0.42	3.43	0.92	0.3	4.77
16	*Syzygium cumini*	Myrtaceae	3.33	5.49	4.59	0.096	13.41
17	*Tamarindus indica*	Fabaceae	0.83	6.86	0.92	0.6	8.61
18	*Tectona grandis*	Lamiaceae	2.5	4.12	4.59	0.07	11.20
19	*Terminalia arjuna*	Combretaceae	1.25	3.43	2.75	0.1	7.43

Table 8.4 Phytosociological analysis of tree species in Rupganj forest

Sl.no.	Species	Family	RD	RA	RF	A/F	IVI
1	*Acacia auriculiformis*	Mimosaceae	8.13	10.61	9.99	0.08	28.75
2	*Aegle marmelos*	Rutaceae	11.00	12.76	11.25	0.09	35.02
3	*Azadirachta indica*	Meliaceae	25.36	11.51	28.75	0.03	65.62
4	*Dalbergia sissoo*	Papilionaceae	1.44	7.49	2.49	0.23	11.43
5	*Phoenix sylvestris*	Arecaceae	0.96	9.99	1.25	0.6	12.19
6	*Phoenix acaulis*	Arecaceae	3.35	11.65	3.75	0.23	18.75
7	*Shorea robusta*	Dipterocarpaceae	44.49	16.01	36.25	0.03	96.76
8	*Syzygium cumini*	Myrtaceae	4.31	14.98	3.75	0.3	23.04
9	*Terminalia arjuna*	Combretaceae	0.96	4.99	2.49	0.15	8.45

8.4.1 Economic Values Plants

The two studied forests comprised a large number of economically important plants and used for various purposes such as medicine, food, timber, and ornamental plants which are described in Table 8.10, and the long-term usage of which may create a path for the indigenous people's economic well-being.

Table 8.5 Phytosociological analysis of different herb species in Pardaha forest

S. No.	Species	Family	RD	RA	RF	A/F	IVI
1	*Abrus precatorius*	Fabaceae	0.46	2.21	0.49	0.45	3.16
2	*Acalypha indica*	Euphorbiaceae	0.85	1.16	1.72	0.07	3.72
3	*Achyranthes aspera*	Amaranthaceae	2.38	2.53	2.21	0.12	7.12
4	*Alternanthera ficoidea*	Amaranthaceae	4.31	3.43	2.94	0.12	10.68
5	*Alysicarpus ovalifolium*	Fabaceae	0.69	1.65	0.98	0.17	3.33
6	*Amaranthus spinosus*	Amaranthaceae	0.38	1.84	0.49	0.38	2.71
7	*Amaranthus viridis*	Amaranthaceae	1.00	2.39	0.98	0.24	4.37
8	*Andrographis paniculata*	Acanthaceae	3.00	1.69	4.17	0.04	8.85
9	*Blumea lacera*	Asteraceae	1.46	2.33	1.47	0.16	5.26
10	*Boerhavia diffusa*	Nyctaginaceae	0.54	1.72	0.74	0.23	2.99
11	*Cassia tora*	Fabaceae	0.69	1.65	0.98	0.17	3.33
12	*Chrysopogon aciculatus*	Poaceae	1.15	1.58	1.72	0.09	4.45
13	*Sida cordifolia*	Malvaceae	4.69	3.45	3.19	0.11	11.33
14	*Sida longifolia*	Malvaceae	2.08	1.65	2.94	0.06	6.67
15	*Sida rhombifolia*	Malvaceae	0.84	1.62	1.23	0.13	3.69
16	*Cleome viscosa*	Cleomaceae	1.00	1.91	1.23	0.16	4.14
17	*Cocculus hirsutus*	Menispermaceae	0.23	1.10	0.49	0.23	1.82
18	*Croton bonplandianum*	Euphorbiaceae	0.54	1.72	0.74	0.23	2.99
19	*Cynodon dactylon*	Poaceae	19.77	6.29	7.35	0.09	33.42
20	*Cyperus esculentus*	Cyperaceae	2.23	1.64	3.19	0.05	7.06
21	*Cyperus rotundus*	Cyperaceae	9.31	3.17	6.86	0.05	19.35
22	*Eclipta alba*	Asteraceae	0.69	1.65	0.98	0.169	3.33
23	*Elephantopus scaber*	Asteraceae	0.85	1.62	1.23	0.13	3.69
24	*Eragrostis tenella*	Poaceae	2.08	2.84	1.72	0.17	6.63
25	*Eupatorium odoratum*	Asteraceae	0.69	1.65	0.98	0.17	3.33
26	*Euphorbia hirta*	Euphorbiaceae	0.54	1.72	0.74	0.23	2.99
27	*Gamochaeta coarctata*	Asteraceae	0.62	1.18	1.23	0.09	3.02
28	*Gomphrena serrata*	Amaranthaceae	0.69	1.65	0.98	0.17	3.33
29	*Heliotropium indicum*	Boraginaceae	0.85	2.02	0.98	0.21	3.85
30	*Hybanthus enneaspermus*	Violaceae	0.92	1.26	1.72	0.07	3.89
31	*Kyllinga nemoralis*	Cyperaceae	6.23	2.84	5.15	0.06	14.21
32	*Lathyrus sativus*	Fabaceae	0.69	2.21	0.74	0.30	3.63
33	*Ludwigia perennis*	Onagraceae	0.92	1.26	1.72	0.07	3.88
34	*Melochia corchorifolia*	Malvaceae	0.46	2.21	0.49	0.45	3.16
35	*Mimosa pudica*	Mimosaceae	2.76	2.21	2.94	0.08	7.92
36	*Ocimum gratissimum*	Lamiaceae	0.69	1.65	0.98	0.17	3.33
37	*Oldenlandia corymbosa*	Rubiaceae	2.46	2.35	2.45	0.09	7.27
38	*Oldenlandia herbacea*	Rubiaceae	0.23	2.21	0.25	0.90	2.68
39	*Peristrophe bicalyculata*	Acanthaceae	1.31	1.39	2.21	0.06	4.90
40	*Portulaca oleracea*	Portulacaceae	0.92	2.94	0.74	0.40	4.60
41	*Ruellia tuberosa*	Acanthaceae	0.69	3.31	0.49	0.68	4.49
42	*Scoparia dulcis*	Plantaginaceae	3.15	1.12	6.62	0.02	10.89

(continued)

Table 8.5 (continued)

S. No.	Species	Family	RD	RA	RF	A/F	IVI
43	*Setaria viridis*	Poaceae	2.23	1.64	3.19	0.05	7.06
44	*Solanum nigrum*	Solanaceae	1.77	1.54	2.6	0.05	6.00
45	*Sonchus oleraceus*	Asteraceae	2.15	1.72	2.94	0.06	6.81
46	*Synedrella nodiflora*	Asteraceae	0.62	1.96	0.74	0.27	3.31
47	*Tephrosia purpurea*	Fabaceae	1.31	1.39	2.21	0.06	4.90
48	*Tridax procumbens*	Asteraceae	5.31	2.03	6.13	0.03	13.47
49	*Triumfetta rhomboidea*	Tiliaceae	0.54	1.72	0.74	0.23	2.99

8.4.2 Various Forest Resources' Livelihood Viewpoints

Throughout field studies, the people's patterns of usage of various forest-based resources were recorded (Table 8.11), and an overview of this is given here. Even during the field survey, up to 50 members of the local forest community were interviewed. Their collection of forest-based products extends from 6 to 14 items.

8.5 Discussion

The presence of 92 species in the Pardaha forest and 67 species in the Rupganj forest is considerably a good statistic, and the tree *Cassia siamea* is evergreen. The two forests were mostly covered by herbs species and are closely followed by trees and shrubs. A similar trend of the result was reported by Balan and Harikrishnan (2017) in which herbs showed a maximum number of species (155). Nayak et al. (2016) also reported 323 plant species genera in Bonaigarh Forest Division, Sundergarh District, Odisha, in northeast India. Because of the habit-heterogeneity, it may be assumed that structural organization will lead to the stability of forest communities. The two forests demonstrate that a high number of genera are found in each. These parameters are indicators that nature is fully supporting biodiversity. According to the findings, it is apparent that the examined forests were provided with a diversity of plant species of various life forms, and their evaluation and recording help enhance conservation strategies. This research also provides information on species diversity, composition, and richness, which change depending on terrain, soil properties, biotic intervention, and climatic conditions. Furthermore, the current study aids in the exploration of several medicinally blessed plant species and their ability to cure various ailments. As a result, the evaluation of these floral resources consists of an inventory of cultivated and non-cultivated plants, woody perennial trees, herbs, and so on. This evaluation can provide information about the amount and quality of key plant habitats that support biodiversity in these investigated forests. *Shorea robusta* has the highest relative density and IVI in the Rupganj forest. Ganguli et al. (2016) found a similar type of outcome in Garhjungle, West Bengal. In the current investigation, the Shannon-Wiener diversity index and Simpson's dominance index

Table 8.6 Phytosociological analysis of different herb species in Rupganj forest

Sl. No.	Species	Family	RD	RA	RF	A/F	IVI
1	*Abrus precatorius*	Papilionaceae	0.363	1.94	0.53	0.30	2.84
2	*Acalypha indica*	Euphorbiaceae	0.82	1.25	1.85	0.06	3.92
3	*Achyranthes aspera*	Amaranthaceae	2.63	3.13	2.38	0.11	8.14
4	*Alternanthera ficoidea*	Amaranthaceae	4.35	3.89	3.18	0.10	11.41
5	*Amaranthus spinosus*	Amaranthaceae	0.18	0.97	0.53	0.15	1.68
6	*Andrographis paniculata*	Acanthaceae	2.99	1.89	4.49	0.03	9.38
7	*Blumea lacera*	Asteraceae	1.54	2.75	1.59	0.14	5.88
8	*Cassia tora*	Caesalpiniaceae	0.99	2.67	1.06	0.21	4.73
9	*Chrysopogon aciculatus*	Poaceae	1.54	2.36	1.85	0.10	5.75
10	*Sida cordifolia*	Malvaceae	5.35	4.41	3.44	0.11	13.19
11	*Sida longifolia*	Malvaceae	2.27	2.02	3.18	0.05	7.47
12	*Cleome viscosa*	Cleomaceae	0.997	2.14	1.32	0.13	4.46
13	*Cocculus hirsutus*	Menispermaceae	0.18	0.97	0.5	0.15	1.68
14	*Croton bonplandianum*	Euphorbiaceae	0.73	2.59	0.79	0.27	4.11
15	*Cynodon dactylon*	Poaceae	22.48	8.03	7.94	0.08	38.45
16	*Cyperus esculentus*	Cyperaceae	2.448	2.018	3.439	0.05	7.91
17	*Cyperus rotundus*	Cyperaceae	10.79	4.13	7.41	0.05	22.33
18	*Eclipta alba*	Asteraceae	0.82	2.19	1.06	0.17	4.06
19	*Eragrostis tenella*	Poaceae	2.18	3.33	1.85	0.15	7.36
20	*Eupatorium odoratum*	Asteraceae	0.73	1.94	1.06	0.15	3.73
21	*Euphorbia hirta*	Euphorbiaceae	0.45	1.62	0.79	0.17	2.87
22	*Gamochaeta coarctata*	Asteraceae	0.54	1.17	1.32	0.07	3.03
23	*Gomphrena serrata*	Amaranthaceae	0.6	1.70	1.0	0.13	3.39
24	*Heliotropium indicum*	Boraginaceae	1.18	3.16	1.06	0.24	5.39
25	*Hybanthus enneaspermus*	Violaceae	0.73	1.11	1.85	0.05	3.69
26	*Kyllinga nemoralis*	Cyperaceae	7.07	3.61	5.56	0.05	16.24
27	*Lathyrus sativus*	Fabaceae	0.64	2.27	0.79	0.23	3.69
28	*Ludwigia perennis*	Onagraceae	0.73	1.11	1.85	0.05	3.69
29	*Melochia corchorifolia*	Malvaceae	0.45	2.43	0.53	0.38	3.41
30	*Ocimum gratissimum*	Lamiaceae	0.73	1.56	1.32	0.09	3.60
31	*Oldenlandia corymbosa*	Rubiaceae	2.63	2.82	2.65	0.09	8.09
32	*Peristrophe bicalyculata*	Acanthaceae	1.72	1.85	2.65	0.06	6.21
33	*Portulaca oleracea*	Portulacaceae	1.27	2.72	1.32	0.17	5.31
34	*Ruellia tuberosa*	Acanthaceae	0.73	3.89	0.53	0.60	5.14
35	*Scoparia dulcis*	Plantaginaceae	2.99	1.19	7.14	0.01	11.32
36	*Setaria viridis*	Poaceae	2.27	1.87	3.44	0.04	7.57
37	*Solanum nigrum*	Solanaceae	1.90	1.86	2.91	0.05	6.67
38	*Sonchus oleraceus*	Asteraceae	2.18	1.94	3.18	0.05	7.29
39	*Tephrosia purpurea*	Fabaceae	0.54	1.94	0.79	0.20	3.28
40	*Tridax procumbens*	Asteraceae	1.18	1.40	2.38	0.05	4.96
41	*Triumfetta rhomboidea*	Tiliaceae	4.44	1.91	6.61	0.02	12.96

Table 8.7 Phytosociological analysis of shrub species in Pardaha forest

Sl. No.	Species	Family	RD	RA	RF	A/F	IVI
1	*Abutilon indicum*	Malvaceae	0.70	3.24	1.10	0.23	5.05
2	*Ageratum conyzoides*	Asteraceae	15.26	7.03	11.03	0.05	33.32
3	*Anisomeles indica*	Lamiaceae	0.50	3.47	0.74	0.38	4.71
4	*Argemone mexicana*	Papaveraceae	3.72	3.95	4.78	0.07	12.45
5	*Calotropis procera*	Asclepiadaceae	2.11	2.43	4.41	0.04	8.95
6	*Cassia sophera*	Caesalpiniaceae	1.91	4.39	2.21	0.16	8.51
7	*Clerodendrum viscosum*	Lamiaceae	27.81	13.26	10.66	0.09	51.73
8	*Combretum roxburghii*	Combretaceae	1.205	3.33	1.84	0.14	6.37
9	*Crotalaria juncea*	Fabaceae	1.00	3.47	1.47	0.19	5.95
10	*Crotalaria pallida*	Fabaceae	0.80	3.70	1.10	0.27	5.61
11	*Holarrhena antidysenterica*	Apocynaceae	8.94	6.18	7.35	0.07	22.47
12	*Hyptis suaveolens*	Lamiaceae	4.22	3.89	5.52	0.06	13.62
13	*Lantana camara*	Verbenaceae	7.13	3.52	10.29	0.03	20.94
14	*Leonotis viscosum*	Lamiaceae	0.70	4.86	0.74	0.53	6.29
15	*Mimosa himalayana*	Leguminosae	1.91	2.93	3.31	0.07	8.15
16	*Murraya koenigii*	Rutaceae	5.72	4.95	5.88	0.07	16.55
17	*Murraya paniculata*	Rutaceae	0.80	3.70	1.10	0.27	5.61
18	*Parthenium hysterophorus*	Asteraceae	5.72	5.65	5.15	0.09	16.52
19	*Physalis minima*	Solanaceae	0.30	2.08	0.74	0.23	3.12
20	*Ricinus communis*	Euphorbiaceae	0.70	4.86	0.74	0.53	6.29
21	*Solanum xanthocarpum*	Solanaceae	1.51	1.89	4.04	0.04	7.44
22	*Urena lobata*	Malvaceae	3.01	2.19	6.99	0.03	12.19
23	*Ziziphus mauritiana*	Rhamnaceae	2.61	2.41	5.52	0.04	10.53
24	*Ziziphus oenoplia*	Rhamnaceae	1.707	2.622	3.309	0.063	7.638

values are within the published range for tropical forests. Earlier researchers found a diversity (H′) range of 0.83–4.1 for Sal forests. Other researchers found that the concentration of dominance (Cd) ranged from 0.10 to 1 for tropical dry forests (Krishnamurthy et al. 2010; Kumar et al. 2010; Sahu et al. 2012). As we progressed from trees to herbs, the species diversity and richness increased. The dominance of phanerophytes in the two investigated forests is clear, as it is in a tropical monsoon biome. This is a sign of enough rain and a thriving natural economy. This is compared to the percentage distribution of phanerophytes in the flora of different semi-arid and arid regions of India (Mertia and Bhandari 1978) as well as with other regions (Jain and Singh 1984; Pandey et al. 1985). Chamaephytes' relatively greater value suggests a continuous concern for their survival in the face of predation and trumpling by big herbivores and invading cattle. A low number of cryptophytes

Table 8.8 Phytosociological analysis of shrub species in Rupganj forest

Sl. No.	Species	family	RD	RA	RF	A/F	IVI
1	*Allophylus cobbe*	Sapindaceae	1.99	3.69	5.09	0.09	10.79
2	*Calotropis procera*	Asclepiadaceae	0.94	2.80	3.19	0.11	6.93
3	*Cassia sophera*	Caesalpiniaceae	0.73	5.45	1.27	0.53	7.46
4	*Clerodendrum viscosum*	Lamiaceae	1.15	2.85	3.82	0.09	7.83
5	*Eupatorium odoratum*	Asteraceae	1.26	3.74	3.19	0.14	8.18
6	*Holarrhena antidysenterica*	Apocynaceae	46.44	22.99	19.11	0.15	88.54
7	*Hyptis suaveolens*	Lamiaceae	0.84	2.49	3.19	0.09	6.51
8	*Ilex* sp.	Aquifoliaceae	24.00	13.21	17.19	0.09	54.41
9	*Lantana camara*	Verbenaceae	0.63	3.11	1.91	0.20	5.65
10	*Mimosa himalayana*	Leguminosae	3.88	3.60	10.19	0.04	17.67
11	*Physalis minima*	Solanaceae	0.31	2.34	1.27	0.23	3.92
12	*Prunus laurocerasus*	Rosaceae	8.59	6.72	12.10	0.07	27.42
13	*Saccharum ravennae*	Poaceae	3.46	12.84	2.55	0.62	18.85
14	*Sesbania cannabina*	Fabaceae	0.73	3.63	1.91	0.23	6.28
15	*Urena lobata*	Malvaceae	1.57	2.59	5.73	0.06	9.90
16	*Ziziphus mauritiana*	Rhamnaceae	1.68	4.15	3.82	0.13	9.65
17	*Ziziphus oenoplia*	Rhamnaceae	1.78	3.78	4.46	0.10	10.02

Table 8.9 Diversity index values of different layers of vegetation in Pardaha and Rupganj forest

		Shannon	Simpson	Evenness	Margalef	Equitability
PARDAHA	Tree	1.992	0.7703	0.3857	3.284	0.6764
	Harb	3.306	0.9337	0.5566	6.694	0.8494
	Shrub	2.533	0.8736	0.5246	3.332	0.797
RUPGANJ	Tree	1.573	0.719	0.5359	1.497	0.7161
	Harb	3.088	0.9177	0.5351	5.715	0.8316
	Shrub	1.757	0.7156	0.3408	2.332	0.6201

indicate that certain environmental stress factors are prevalent, which is aided by an open canopy. However, it is unlikely that one could hear the doorbell of a desert shortly. Therophytes in the region have a numerical strength similar to that of the normal spectrum. Because hemicryptophytes function as soil binders, their presence indicates a low degree of soil erosion in these forest areas. Cryptophytes are low, suggesting that environmental conditions are conducive for the plant species' development. However, the presence of few chamaephytes indicates that the forest has deteriorated and is on its way to desertification. The strength of cryptophytes shows the need to save water and improve soil water-holding capacity. Overgrazing, indiscriminate tree felling, and unreasonable removal of plant parts and products must be prevented, and additional stressors must be recognized to take suitable remedial actions. In addition, biodiversity must be sustained collaterally with modernization via scientific management. Many trees and crops on these two studied forests can sequester atmospheric carbon and deposit it in plant parts as biomass,

Table 8.10 Uses of the species in Pardaha and Rupganj forest

Sl. no	Species	Uses
1	*Abrus precatorius*	Seeds are antiperiodic, diaphoretic, purgative. Seeds are used externally in the treatment of hair loss, leprosy, sciatica
2	*Abutilon indicum*	The juice of the leaves is demulcent and diuretic. Flowers are used to treating fever, colic
3	*Acacia auriculiformis*	The root is used to treat aches and pains. Acacia contains greater quality of astringent and tannins
4	*Acalypha indica*	The plant has much traditional medicinal use; shoots and leaves are edible; the plant shows antifungal activities against plant pathogen
5	*Achyranthes aspera*	It is used in boils, cough; useful in renal dropsy and bronchial affections. It is useful as purgative and diuretic and for skin eruptions and snake bite
6	*Aegle marmelos*	Fruits can be eaten. Young leaves have astringent properties and can be used to heal peptic ulcers
8	*Albizia lebbeck*	Leaves and seeds are used in the treatment of eye problems. The flowers are applied locally to skin eruptions. The powdered seeds are used to treat scrofula
9	*Alstonia scholaris*	It is anthelmintic, anticholinergic, astringent
10	*Amaranthus spinosus*	Young shoots are used as a vegetable and as fodder. Roots are used in menorrhagia, eczema, colic, and lactation
11	*Amaranthus viridis*	Leaves cooked like spinach
12	*Andrographis paniculata*	Leaves or roots are used against stomachache, dysentery, cholera, influenza. It is considered to be anti-inflammatory and immunosuppressive. Leaves are used in the treatment of fever and for itching skin eruptions
13	*Anisomeles indica*	The plant is used in the treatment of cold fevers, skin sores. Leaves are used to treat uterine infections, kidney gravel and hypertension
14	*Azadirachta indica*	Leaves are edible, used as medicine, antifungal
15	*Blumea lacera*	Leaves are cooked and eaten as a vegetable. Fresh flowers are given before meals to treat bronchitis. The leaves are astringent, diuretic, and stimulant
16	*Boerhaavia diffusa*	Stems, roots, and seeds are edible. Used in traditional medicine
17	*Borassus flabellifer*	Fruits are edible. Young roots are anthelmintic and diuretic. The whole plant is medicinally important
18	*Calotropis procera*	The root bark is an emetic. The leaves are used for the treatment of asthma. The bark powder is used in the treatment and cure of leprosy
19	*Cassia fistula*	The common cold problem can be relieved by using this plant. It cures fever. Leaves are used in relieving skin irritation
20	*Cassia siamea*	The leaves, tender pods, and seeds are edible. As a hardwood, it is used for ornamentation
21	*Cassia sophera*	An infusion of the bark is used in the treatment of diabetes. Leaves are anthelmintic, expectorant. Seeds are used to reduce fever
22	*Cassia tora*	It is very useful in treating skin problems. Leaves and seeds are very useful in leprosy, colic, cough, and cardiac disorder. Fruit is used in the treatment of fever

(continued)

Table 8.10 (continued)

Sl. no	Species	Uses
23	*Chrysopogon aciculatus*	The straw is used for weaving mats, hats, brushes, small cases, etc.
24	*Cleome viscosa*	The leaves are used to treat wounds and ulcers. The seeds are used to treat piles. Leaves and young shoots are edible
25	*Crotalaria juncea*	Source of natural fiber and biofuel, helps in nitrogen fixation
26	*Croton bonplandianu m*	Traditional Chinese medicine
27	*Cynodon dactylon*	The plant is used to treat all types of bleeding and skin troubles. The shoot apex may produce cyanogenic glycosides
28	*Cyperus esculentus*	Edible oil is obtained from the tuber. The tubers are said to be aphrodisiac, carminative, and diuretic
29	*Cyperus rotundus*	The roots and tubers have analgesic and antibiotic properties
30	*Dalbergia sissoo*	The leaves are used as a stimulant and to treat gonorrhea and wounds. The roots and seeds are used medicinally
31	*Eragrostis tenella*	It is grazed by cattle and water buffaloes in traditional feeding systems. It has minor agricultural importance
32	*Eupatorium odoratum*	It is used to treat the castration wound in the piglet
33	*Euphorbia hirta*	It is used in the treatment of dysentery, syphilis, skin conditions, bronchitis, asthma, cough, colds
34	*Ficus hispida*	The bark is anti-periodic, emetic, and tonic. The root is used in the treatment of fever
35	*Ficus religiosa*	The leaves and twigs are alternative, antidote, astringent, and laxative. The aerial roots are diuretic
36	*Gamochaeta coarctata*	Used in medicines
37	*Heliotropium indicum*	Leaf juice is used in conjunctivitis
38	*Hemidesmus indicus*	Root extract is used as a flavoring agent. Roots and leaves are used in Indian herbal medicine
39	*Holarrhena antidysenterica*	It is used for the treatment of colic, skin disease, dysentery, and urinary tract infection
40	*Kyllinga nemoralis*	It is used in traditional folk medicine to treat many diseases and disorders
41	*Lantana camara*	The bark is used as a treatment for fevers and inflammations of the uterus. Leaves and stems are used to treat eczema, measles, and chicken pox rashes
42	*Ludwigia perennis*	Leaves are cooked and eaten as vegetable
43	*Madhuca longifolia*	The bark is used medicinally. Leaves are edible
44	*Mangifera indica*	The roots are diuretic. Fruits are antiscorbutic and antidysenteric. The stem is used to treat diarrhea
45	*Melochia corchorifolia*	Stem and leaves are boiled in oil and used in bites of snakes. Stem gives fiber

(continued)

Table 8.10 (continued)

Sl. no	Species	Uses
46	*Mikania scandens*	A tea made from the whole plant is used as a treatment for stomachaches and to clean out the uterus. The stem and leaves are used as a remedy to treat malaria and eczema
47	*Mimosa pudica*	It helps in the treatment of many disorders like piles, dysentery, etc.
48	*Murraya koenigii*	Leaves are used to flavor curries. Leaves, roots, and bark can all be used in the treatment of digestive problems
49	*Murraya paniculata*	Leaves are used to flavor curries
50	*Ocimum gratissimum*	An essential oil obtained from the leaf showed marked antibacterial activity. Leaves are used in the treatment of a cold
51	*Oldenlandia corymbosa*	The tender young leaves and stems are cooked with other vegetables. The entire plant is used as an anthelmintic, antirheumatic, depurative, digestive, pectoral, and stomachic
52	*Oxalis corniculata*	Leaves – raw or cooked as a vegetable. The whole plant is anthelmintic, antiphlogistic, astringent, depurative, diuretic, and it is used in the treatment of influenza, fever, diarrhea, and poisonous snake bite
53	*Peristrophe bicalyculata*	It is used in the treatment of the eye and ear. The plant is antibiotic, bacteristatic, fungistatic
54	*Parthenium hysterophorus*	Used in traditional medicine to treat fever, diarrhea, dysentery, malaria, urinary tract infection
55	*Polyalthia longifolia*	The inner bark is a good bast fiber. It has been used in making barrels
56	*Portulaca oleracea*	Used as a vegetable in scurvy and liver diseases. Seeds are vermifuge, and stem juice is applied to prickly heat
57	*Ricinus communis*	Castor oil has many uses in medicines. Used for insecticidal activities
58	*Scoparia dulcis*	It is used for treating diabetes, coughs, fever, and skin problems. It is also used as a sand binder
59	*Setaria viridis*	The seed is diuretic, emollient. The plant is crushed and mixed – used in the treatment of bruises
60	*Sida cordifolia*	Leaves are given in diarrhea during pregnancy. Crushed leaves are applied on cuts and bruises
61	*Sonchus oleraceus*	The roots are abortifacient, purgative, and vermifuge. The leaves are applied to inflammatory swellings
62	*Streblus asper*	Roots are used to treat diphtheria and toothache. Leaves are depurative and laxative
63	*Synedrella nodiflora*	Crushed leaves have been used as a treatment for rheumatism. Young shoots are edible as a vegetable
64	*Tamarindus indica*	The fruit is aperient and laxative. Powdered seeds may be given to cure dysentery and diarrhea
65	*Tectona grandis*	The bark has been used in the treatment of bronchitis. The wood is an excellent timber for bridge building, house building
66	*Tephrosia purpurea*	It is used as a treatment against dyspepsia, colic, and chronic diarrhea. The fruit extract is used to relieve body pain. The roots are bitter and anthelmintic

(continued)

Table 8.10 (continued)

Sl. no	Species	Uses
67	*Terminalia arjuna*	The juice of the bark is used as a tonic. The gum is used medicinally
68	*Tridax procumbens*	The leaves are hemostatic and used as parasiticide
69	*Urena lobata*	The plant is used in traditional medicine as a source of fiber
70	*Ziziphus mauritiana*	Fruits are edible; leaves are used as fodder, a source of timber
71	*Ziziphus oenoplia*	Used in herbal medicine

Table 8.11 An account of different forest products used by the forest dwellers

Collected forest products by the forest dwellers	Consumed by the community itself
Leaf of different plants (especially Sal), the flower of Mohul plant, fruits, vegetables, wood, ornamental plants, wild animals, various parts medicinal plants, resin, etc.	Yes

Table 8.12 Most important tree species in the two studied forests and their carbon sink values

Different tree species	Carbon sink potential	References
Dalbergia sissoo (Sissoo)	152.0 tons per tree	Bilyaminu and Wani (2016)
Albizia lebbeck (Siris)	158.2 tons per tree	Bilyaminu and Wani (2016)
Dalbergia sissoo (Sissoo)	27.3 ton/hectare/year	Sheikh et al. (2015)
Dalbergia sissoo (Sissoo)	3.6 Mt per year	Raizada et al. (2003)
Tectona grandis (Teak)	181.0 tons per hectare	Sreejesh et al. (2013)
Albizia lebbeck (Siris)	12.0 tons per hectare	Jana et al. (2009)
Shorea robusta (Sal)	8.9 tons per hectare	Jana et al. (2009)
Mangifera indica (Mango)	104.4 tons per hectare	Chavan and Rasal (2012)

therefore aiding in carbon balance in the ecosystem and mitigating climate change. As a result, these woods are home to several essential species that have a remarkable potential to store carbon. Dhruw et al. (2009) underlined the carbon sequestration capacity of several tree/crop species. In these two forests, *Dalbergia sissoo*, *Tectona grandis*, *and Cassia siamea*, among others, play an important role in microclimate amelioration through climate change mitigation. Sheikh et al. (2015) also lauded *Dalbergia sissoo* (Sissoo), for its better efficiency in preserving environmental security owing to its high potential for carbon sequestration and climate change mitigation. However, the two forests were endowed with many leguminous tree species that differed in carbon sequestration capacity according to various researchers (Table 8.12). As a result of the existence of these vital species, the two forest regions have a healthy ecosystem and microclimate.

Forest inhabitants were seen collecting numerous plant components without falling trees and using them for a variety of purposes including food, medicine, fodder, fiber, and gums, as well as for agricultural purposes. Different plant components such as roots, leaves, whole plant, dried branches, seeds, etc. were observed to be used by ethnic communities to obtain benevolence from various species. If any such usage is not restricted, negative consequences will inevitably be passed on to the people, threatening its sustainability. A lot of species wherein the vegetation is fully uprooted or the reproductive organs are actively utilized should be evaluated if these problems are to be managed. Not just due to their destitution but also for the high instability and inadequacy of agricultural production, the bulk of the people was observed to rely on a large number of palatable native plants. These financially disadvantaged people's traditional knowledge of how to use wild plants for food and sustenance should be recognized and appreciated. The underlying concepts of these edible native plants require scientific inquiry not just to solve food security problems but also to fulfill human nutritional requirements. Arora and Pandey (1996), realizing this, have promoted the usage and protection of wild food plants in India. Despite being primarily used as food, the majority of the plant species contain therapeutic qualities. So, forests must be deliberately restored in tandem with the economic well-being of the people who live nearby.

8.6 Conclusion

The documentation of floral diversity is gaining traction, and it includes many stages of research such as phytodiversity assessment, protection and restoration methods, and sustainable usage among people. The investigated forest region is provided with a high diversity of plants with diverse life forms of high aesthetic value, resource value, and ecological distinctiveness. Through the identification of leguminous plants, the variety of plants in the investigated forests provides several ecosystem services that aid in the maintenance of food-soil-climate security. The flora of Pardaha and Rupganj resembles that of the Gangetic plains in general. As a result, it is fair to infer that frequent vigilance of the flora, as well as the biological spectrum, is necessary for more productive conservation and sustainable utilization strategies based on these forests. In terms of floristic diversity, the findings are quite positive. The forest's accommodative capacity is fairly broad since it supports a high level of taxonomic variety, as evidenced by its high generic co-efficient value. The biological spectrum of the Pardaha and Rupganj forest indicated that they had the same sort of phytoclimate. Both forests were being dominated by phanerophytes, but the decreased value of the other life types indicates forest degradation. The decreasing value of chamaephytes and the growing value of therophytes indicates desertification and habitat fragmentation (Dutta et al., 2017). These forests require rapid restoration. Surprisingly, several of the forest species have a wider ecological distribution and are more adaptive. This evolution enhances the likelihood of natural regeneration in these forests and the capability for it. As a consequence, the findings of this study have the potential to make a major difference by exposing the current state of plant variety, vegetation, and the highly competitive character of many invasive and opportunist species (*Lantana* sp.). The biological richness of these forests is exceptional, implying far-reaching consequences that must be addressed. This research will aid in the resolution of this problem and give a framework for other academics and policymakers seeking relevant information on forest inventory and its recommendations for future conservation initiatives. Forest inhabitants rely heavily on the forest and its direct services, which are given in the form of a variety of physical items, and play a significant role in providing vital sources of livelihood and food to forest-dwelling people. Prioritize research into the nature of different forest resources, their collecting intensity, marketing mechanisms, processing, and long-term practices using the optimum management method. These economically important species from a tribal perspective should be incorporated in new plantation plans near their habitat to ensure a steady supply in the future. Forests provide a major economic benefit to forest dwellers in the form of livelihood, though it can lead to forest resource depletion. So, there should be appropriate forest resource monitoring and management framework in place. Furthermore, forest-dwelling people should be educated and trained on sustainable forest harvesting so that forest resources may be used wisely and managed sustainably. Furthermore, forest fire and encroachment prevention should be managed in a collaborative strategy involving forest agencies and local community stakeholders. The availability of markets for selling products, infrastructure, accessibility, market and trade connection, regulatory framework, and other factors all contribute to the sluggish growth and development of forest-based enterprises. As a result, it should be addressed through a well-thought-out strategy for the correct growth and development of forest-based enterprises, which would provide several opportunities for local stakeholders. Further, greater scientific investigation of forest resources with production potential, as well as the impact of harvesting on this ecosystem, should be conducted to provide the necessary data for developing action plans and management regimes. For non-timber forest product extractions, the practice of sustainable harvesting should be promoted. Further, some relaxation and suitable livelihood options should be given to the forest-dwelling population whose habitation is nearby protected forest. Further, the government should explore the opportunities and possibilities toward tribal developmental policies, plans, and developmental programs for more economic gain.

International forest policy has recognized the value of traditional forest knowledge, as well as the usefulness and necessity of taking this understanding into account when developing plans and practices for the protection and conservation of forests. Furthermore, the study site's previous history of overexploitation of forests, primarily for timber; formation of industries and associated capacity development; scarcity of water, particularly in the summer; and other factors have slowed socioeconomic growth. Existing circumstances must be rectified by conserving soil and native tree species, as well as concurrent eco-restoration and ultimate security of the forests' assets. The only hopeful feature noted by the author is the increased knowledge of ethnic peoples about the current situation of their woods and their concern for their subsistence. It is not unlikely that their hunger makes them hostile to forests, and any effort to safeguard existing forests must begin with the protection of forest inhabitants' existence. As a result, it is critical to implement an integrated resource conservation strategy that allows the tribal economy to flourish in tandem with the forest economy by making the best possible use of resources while adhering to natural rules. The proper supervision must include measures for natural resources and environmental preservation so that forest flora and wildlife can continue to provide resources while maintaining a high level of diversity, richness, and usefulness (Gupta et al., 2021). It must draw on indigenous tribes' traditional wisdom, as well as forest officials' and scientists' competence while remaining in tune with nature's self-designing potential.

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Part III
Forest Management

Chapter 9
Assessment of Forest Cover Change, Community Responses, and Conservation Strategy: Evidence from North Sikkim District, India

Sushmita Chakraborty and Arunima Chanda

Abstract In this chapter we are studying three important issues which have global concerns, i.e., spatiotemporal assessment of vegetation dynamics, responses of local community in forest management practices, and prospective conservation strategies. To understand the vegetation dynamics, we have used multi-temporal satellite data and have found that forest areas are continuously decreasing from south to north in North Sikkim. Due to strict legal protocols, dense forest cover is least degraded forest here since the last 30 years. Data shows that moderate and open forest cover are changing due to increasing anthropogenic and natural disaster. JFMC/EDC acts as a significant body encouraging local community to participate in forest management practices. We have also tried to propose HCV model as a potential conservation strategy here. The research findings underscore the necessity for further policy implementation to fight rural poverty, equal forest access, active participation, and holistic management of biodiversity especially for this biological hotspot.

Keywords Forest · Indigenous communities · Management · HCV

Abbreviations

BP	Below poverty Line
CF	Community Forestry
DEM	Digital Elevation Model
DFO	District Forest Officer
EDC	Economic Development Committee
FLII	Forest Landscape Integrity Index

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FSI	Forest Survey of India
GPU	Gram Panchayat Unit
HCV	High Conservation Value
IIPS	Indian Institute for Population Sciences
ISFR	India State Forest Report
ITTO	The International Tropical Timber Organization
JFM	Joint Forest Management
LULC	Land Use and Land Cover
NDVI	Normalized Difference Vegetation Index
NFHS	National Family Health Survey
NP	Nagar Panchayat
NTFP	Non-timber Forest Product
OLI	Operational Land Imager
OLS	Ordinary Least Square
PRI	Panchayati Raj Institution
RS-GIS	Remote Sensing and GIS
SC	Schedule Caste
SFM	Sustainable Forest Management
ST	Schedule Tribe
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
WWF	World Wildlife Fund

9.1 Introduction

Forests are critical to sustainable development (United Nations 2015; United Nation Framework Convention on Climate Change 2016). Global loss of tree cover represents a serious environmental issue (Hansen et al. 2013) and it is the prime cause of extinction of biotic communities from global biodiversity hotspots. The total area of degraded forest in the tropic has been estimated at around 500 million hectares and emphasis has been given to reduce the rate of deforestation (Sahana et al., 2021; ITTO 2012). Eastern Himalaya, located in a tropical region, is the nucleus of a variety of flora and fauna where forest cover change is directly linked with climate change, carbon cycle, loss of biodiversity, and agriculture (Babbar et al., 2021; Feddema et al. 2005). Out of 34 biodiversity hot spots in the world recognized by UNESCO, India owns 2, one is in the Western *Ghats* and second one is in the Eastern Himalaya. Sikkim owns the country's 26% of total biodiversity (Forest and Environment Department, Government of Sikkim, 2017). North Sikkim district is one of the ecologically sensitive areas. Globally, the diversity of local practices, community ethos, and social institution contribute to biodiversity management (Long and Zhou 2001). Comprehensive conservation strategy would help to preserve natural resource (Sahana et al., 2018) and will protect the wellbeing and livelihood of local communities. This chapter tries to highlight two research questions, i.e., What are the assessment techniques of forest dynamics? And what is the community participation scenario along with potential conservation strategy?

Assessment of vegetation dynamics by using RS-GIS technique has global implication to understand the responsible climatic and anthropogenic factors (Suzuki et al. 2001; Sen and Yuan 2007; Karlsen et al. 2008; Zeng et al. 2013; Wang et al. 2010). This chapter shows a clear gradient of vegetation dynamics from temperate to alpine ecosystem and temporal variation of vegetation cover is relevant to detect the trend of forest density changes. LULC mapping here is useful from environmental and socioeconomic point of view and application of RS-GIS technique has made it more accurate. This technique can detect, identify, monitor, and map differences in land use over time (Yuan et al. 2005) which has significance in policy decision-making and planning purpose. Community forestry concept on the other hand is getting importance for the last few years (Food and Agricultural Organisation, 2010), and over half a billion people in developing countries are now dependent on community-based forests (Agarwal 2007). It has widespread socioeconomic, environmental, and political concerns (Timsina et al. 2004). Active forest management by local communities maintains a regular supply of forest products and stimulates awareness and collective responses (Chhetri et al. 1993, 2013). This research would help to identify the pattern and tendencies of community's behavior through which further a theoretical framework of forest management could be constructed.

There exists a dearth of literature in this context in North Sikkim. Sikkim Forest, Environment and Management Department (2017) has identified active and passive drivers of deforestation. Increasing tourism pressure in the trekking corridors has an impact on firewood loss and resource degradation (Chettri et al. 2002). Kanade and John (2018) highlight the role of topographical factors on land use decision and declination of tropical montane forests in lower elevation zone of Sikkim by using satellite images. Chettri et al. (2015) describe different aspects of community forest management in Sikkim.

This chapter has multiple contributions to make. First, there are no studies in North Sikkim that document temporal and spatial forest cover assessment by using RS-GIS techniques. Clear depiction of vegetation dynamics would help researchers and policymakers to think about comprehensive management strategies. Both increasing and decreasing trend of forest cover need proper conservation strategies for sustaining biodiversity. Secondly, this is the first research work which tries to understand community perception and participation scenario in forest management covering 15 remote villages. Thus, this research seeks to identify three broad objectives. Firstly, to assess forest cover dynamics by using satellite data, secondly, to discuss local community responses, and finally to propose sustainable forest management strategies for future development.

9.2 Study Area

Sikkim, a small mountainous state, is situated at the north-eastern pocket of India. This state has witnessed a long history of sociopolitical upheaval. After 333 years of the Namgyal dynasty, Sikkim has become a part of the Indian Union in 1972. Four districts of Sikkim are named according to their regional location and they are North, East, South, and West district. The North district of Sikkim (Fig. 9.1) is situated in the womb of famous Mt. Kanchenjunga (8598 meters, the third highest peak in the world) which is further subdivided into two subdivisions, Chungthang and Mangan. Chungthang subdivision is entirely rural without having a single town within its jurisdiction (Fig. 9.2). Geological complexity, rigorous climate, and remote and inaccessible location lead to sparse population distribution. The only town is Mangan (Nagar Panchayat (NP) and district headquarter) situated in the Mangan subdivision (Fig. 9.2). The North district has the largest areal coverage (4226 sq.km, Census of India, 2011) with the least population density (10 persons per sq. km as per Census of India, 2011). This district consists of 89.38% rural population and 10.62% urban population (District Census Handbook, 2011). Elevation varies from 494 mt in the south to 8598 mt in the north and the district is desolate and bleak without any sign of healthy vegetation. Slope is an important factor for triggering landslide here which includes slope instability over an area. The steeper the slope, the more are the chances of earthquake occurrences. Steep and rocky slopes are also unfit for agriculture. Glacier and glaciated areas, barren rock-talus field areas, and

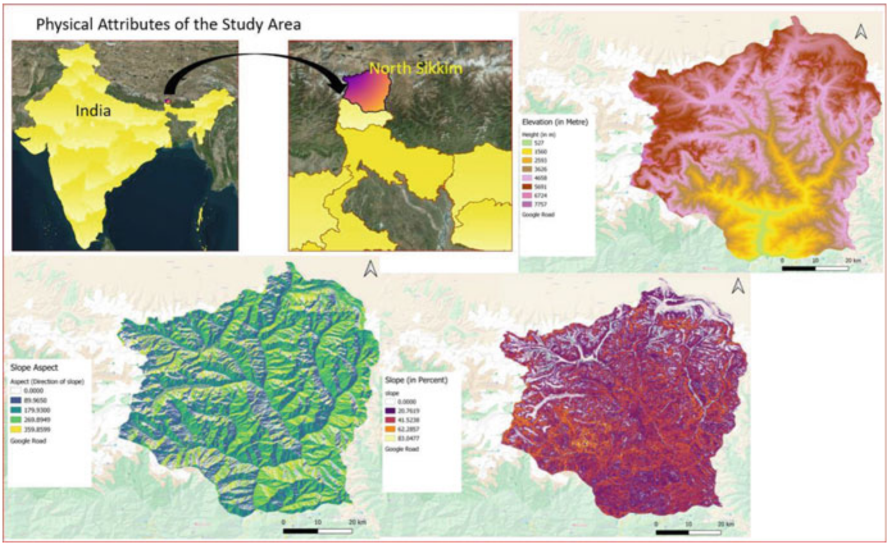


Fig. 9.1 Location of the study area

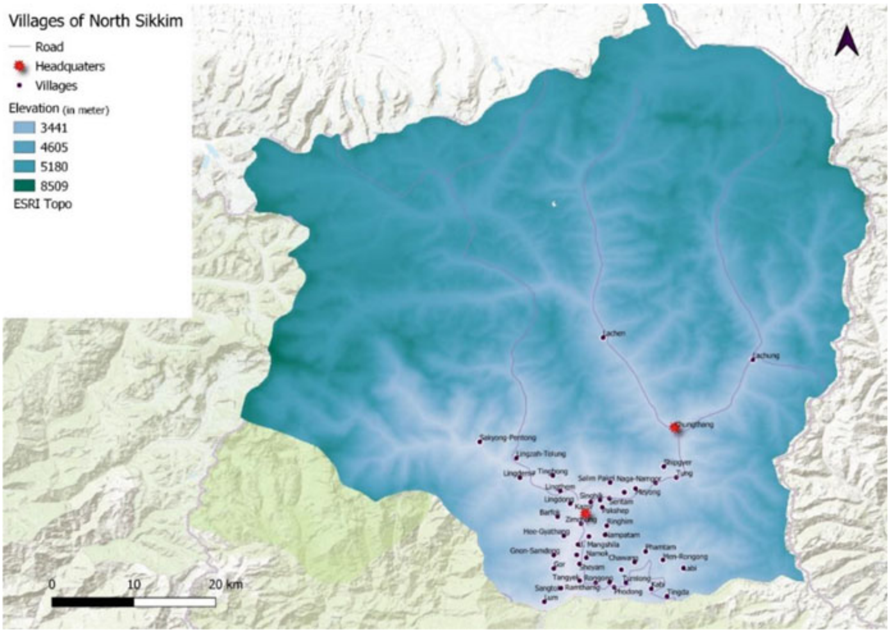


Fig. 9.2 Location of villages, district headquarters, and major transport route in North Sikkim

moraine and alpine meadow areas consist of respectively 19.40%, 24.45%, and 28.40% (Multi-Hazard Risk and Vulnerability Assessment Report, North Sikkim 2015). This multiethnic district consists of two major indigenous communities, i.e., Lepcha and Bhutia (Bhasin 2011), who are Buddhist by religion and scheduled tribe by caste (Sikkim Human Development Report 2014). According to the National Family Health Survey (NFHS 4) 2015–2016, the percentage of Buddhist religion population is high 63.70%, followed by Hindu (29.87%) and Christian (5.46%). In this district, 78.20% of the population is a scheduled tribe, 10.53% is other backward class, and only 1.93% is scheduled caste (NFHS 4).

According to the Indian State Forest report, 2019, 30.38% of the geographical area is under forest cover where 9.71% is under dense forest, 13.87% is in moderate dense forest, and 6.79% is under open forest. The northern part of the district is mainly covered with a scrub which covers 4.87% of the total geographical area.

9.3 Database and Methodology

The present research (Fig. 9.3) is following a systemic research design and specific query.

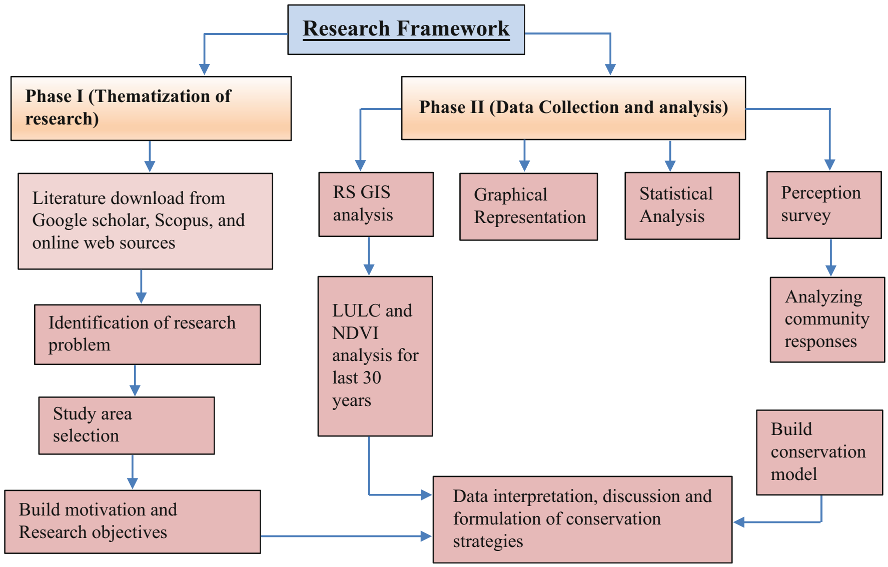


Fig. 9.3 Research methodology framework

9.3.1 Database

The following table (Table 9.1) shows the used satellite images for the present study.

Both primary and secondary data have been used here. Primary data has been collected on a random basis from 3 Gram Panchayat Units (GPUs[1]). Table 9.2 is showing the selected survey location of North Sikkim.

To study the community participation scenario, variables have been identified from field survey. Table 9.3 represents descriptive statistics of selected variables.

9.4 Methodology

9.4.1 Change Detection

Change detection study involves the use of a multi-temporal dataset to discriminate areas of forest cover change between dates of imaging. The uses of remote sensing techniques have immense significance to monitor the changing vegetation of a particular area (Dalmiya et al. 2019; Stehman and Foody 2019). Though there are

[1]The rural administrative unit has its own democratic and political structure. It is a self-governing body in rural areas of India. More information can be obtained from https://legislative.gov.in/constitution-seventy-third-amendment-act-1992 (accessed April, 18; 2021).

Table 9.1 Satellite image description

Sl. no.	Used maps	Data type	Used software	Data acquisition date	Scale	Source
1	Elevation map (mt)	ALOS Palsar	QGIS	09-12-2009	12.5 m	Earth Data
2	Slope in aspect	ALOS Palsar	QGIS	10-12-2009	12.5 m	Earth Data
3	Slope in percentage	ALOS Palsar	QGIS	11-12-2009	12.5 m	Earth Data
4	Location of settlement and major transport route	KML	QGIS	12-12-2009		
5	Protected natural reserve	KML	QGIS	2020	kml	DIVA GIS
6	LULC 1991	Landsat 4–5 TM	Erdas Imagine	14-10-2017	30 m	Earth Explorer
7	LULC 2001	Landsat 4–5 TM	Erdas Imagine	15-12-2016	30 m	Earth Explorer
8	LULC 2011	Landsat7 ETM	Erdas Imagine	17-10-2011	30 m	Earth Explorer
9	LULC 2021	Landsat 8 OLI	Erdas Imagine	14-09-2021	30 m	Earth Explorer
10	NDVI 1988	Landsat 4–5 TM	Erdas Imagine	09-02-2017	30 m	Earth Explorer
11	NDVI 2000	Landsat 4–5 TM	Erdas Imagine	15-12-2016	30 m	Earth Explorer
12	NDVI 2010	Landsat7 ETM	Erdas Imagine	14-09-2021	30 m	Earth Explorer
13	NDVI 2021	Sentinel 2A	Google Earth Engine	16-03-2021	10 m	Google Earth Engine

Compiled by authors

different vegetation indices used to monitor forest health, for the present study, NDVI image analysis technique has been used which is reliable and has been used widely since the last few decades (Lyon et al. 1998; Campbell and Wynne 2011). In this technique infrared bands are used for monitoring vegetation health. NDVI values from reflectance images have been obtained by means of channels 3 (red, 0.63–0.69 μm) and 4 (near-infrared, 0.77–0.90 μm). NDVI value ranges from −1 to +1. From Eq. (9.1), NDVI has been calculated.

$$\mathrm{NDVI} = (\mathrm{NIR} - \mathrm{RED})/(\mathrm{NIR} + \mathrm{RED}) \tag{9.1}$$

Forest cover change detection has also been studied by using forest cover change data provided by the India State Forest Report (ISFR) by Forest Survey of India. They have used IRS Resourcesat-2 satellite where they have classified forest canopy density classes into three categories, i.e., very dense forest, moderate dense forest, and open forest. To study the landscape change in North Sikkim, we have also used

Table 9.2 Survey areas of North Sikkim

Name of subdivision	Name of GPUs	Survey areas (villages)
Chungthang	Lachen	Lachen Dzumsa
	Lachung	Lachung Dzumsa
	Chungthang	Chungthang
Mangan	Singhik	Pakshep
		Kazor
		Sentam
	Hee-Gyathang	Gnon-Samdong
		Hee-Gyathang
	Barfok Lingdom	Barfok
		Lingdong
	Mangshila Tibuk	U. Mangshila
		L. Mangshila
	Kabi Tingda	Kabi
		Tingda
	Phensong	Paney-Phensong
		Labi
	Ramthang Tangyek	Tangyek
		Ramthamg
	Lingthem Lingdem	Lingthem
		Lingdem

Source: Compiled by the author

land use and land cover change technique from 1991 to 2021. The classification schemes include settlement area, open land/snow-covered area, agriculture/low vegetation area, dense forest, sub-stream, river, and water body.

9.4.2 Regression Analysis

To show the economic profile of the districts and to control the impact of probable confounders on wealth quintile, a series of socioeconomic and environment indicators have been used from NFHS 4. The survey was conducted in 2015–2016 by the Ministry of Health and Family Welfare through the IIPS, Mumbai, India, and included 640 districts from 29 states and 7 union territories. For North Sikkim, NFHS 4 provides 934 observations. OLS regression which is multivariate regression model has been used here to observe the association among variables. Here, wealth quintile has been taken as a dependent variable, whereas clustered altitude; own livestock, herds, or farm animal; caste/tribe of household head; household has BPL card; female-headed household; age of household head; non-nuclear household; household head religion Buddhist; and highest education level attainment have been taken as independent variables.

Table 9.3 Descriptive statistics of selected variables from primary survey

Sl. no.	Variables	Obs	Mean	Std. dev.	Min	Max
1	Length of membership in JFM/EDC	1573	10.79	4.49	0	20
2	Availability of training facilities to local communities	1573	2.39	0.75	1	3
3	Ecological and scientific knowledge of local communities	1573	2.26	0.6	1	3
4	Representation of household members in JFM/EDC	1573	1.6	0.86	1	6
5	Ability of local communities to participate in forest management programs	1573	1.82	0.7	1	3
6	Educational attainment and level of involvement of local communities in JFM/EDC	1573				
6.1	No education/pre-education: high – 3, medium – 2, low – 1		1.42	0.63	1	3
6.2	Primary: high – 3, medium – 2, low – 1		1.59	0.71	1	3
6.3	Secondary: high – 3, medium – 2, low – 1		2.23	0.8	1	3
6.4	High: high – 3, medium – 2, low – 1		2.39	0.83	1	3

*Obs – No. of respondents
2) Satisfied – 3, moderately satisfied – 2, not satisfied – 3
3) Sufficient – 3, moderately sufficient – 2, insufficient – 3
5) Confident – 3, moderately confident – 2, less confident – 1

Source: compiled by the authors

The OLS equation is as follows:

$$Y = \alpha + \beta x_1 + \beta x_2 + \beta x_3 \ldots\ldots \beta_n \ldots\ldots\ldots\ldots\ldots\ldots \quad (9.2)$$

$$Y = Wealth\ quintile\ as\ a\ dependent\ variable, \alpha = intercept$$
$$and\ \beta = slope\ of\ the\ line, x = independent\ variables.$$

Summary statistics of the considered variables from NFHS4 have been listed here (Table 9.4).

9.4.3 Joint Forest Management and High Conservation Value as a Method of Forest Conservation and Management

Forest is an integral part of Sikkim's livelihood and environmental security. Decentralization of the State Forest Department got momentum in Sikkim in 2002 with the formation of 155 JFMC and 49 EDC. Joint Forest Management is an implementing agency at a village level registered by the concerned territorial division forest office. JFM in Sikkim aims to protect natural forest and maintain biodiversity. JFM

Table 9.4 Summary statistics

Variables	Obs	Mean	Std. dev.	Min	Max
Altitude	934	1927.778	987.9764	901	5338
Own livestock, herds, or farm animal	934	0.672377	0.469598	0	1
Caste/tribe of household head	933	991.3644	0.488163	991	993
Household has BPL card	934	0.414347	0.492873	0	1
Female-headed household	934	1.12955	0.335988	1	2
Age of household head	934	45.50535	13.67207	16	98
Non-nuclear household	934	1.302998	0.459801	1	2
Household head religion Buddhist	934	3.667024	1.819698	1	5
Highest education level attainment	934	1.296574	0.979341	0	8
Number of observation – Households numbers					

Source: NFHS4

Table 9.5 Vertical distribution of the trees along with elevation and climate

Type	Elevation (mt)	Average temperature (°C)	Average precipitation (cm)	Average humidity (%)
Temperate broadleaf	1800–2800	15–20	75–125	80
Temperate coniferous	2800–3500	10–15	50–75	60
Sub-alpine	3500–4000	0–10	25–75	40
Moist alpine	4000–5000	Less than 0	10–25 (snowfall is very common)	20–40

ISFR 2019

involves local community at micro level and helps to meet villagers' needs for subsistence and livelihood.

On the other hand, the Forest Stewardship Council (FSC, an independent non-profit organization) envisaged the concept of High Conservation Value Forest (HCVF) in 1993 to promote responsible forest management (Rietbergen-McCracken 2007). HCV aims to provide a framework to identify significant forest areas which have special attributes and which are valuable for particular biodiversity and local community. Researchers and policymakers can apply this management framework for ecologically significant areas where preservation of social and ecological values is utmost needed (Areendran et al., 2020).

9.5 Result

Large variation in climate and vegetation are the unique features of this district. The distribution of the tree here is highly controlled by elevation and climatic conditions (Table 9.5).

9.5.1 Change Detection Using NDVI Technique

For the present study, three time series analyses of NDVI values (1988–2013, 2013–2017, and 2017–2021) have been used (Figs. 9.4, 9.5, and 9.6).

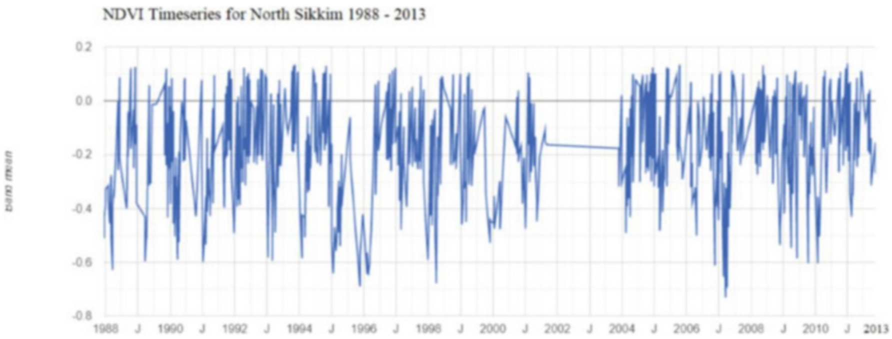


Fig. 9.4 NDVI trend analysis from 1988 to 2013

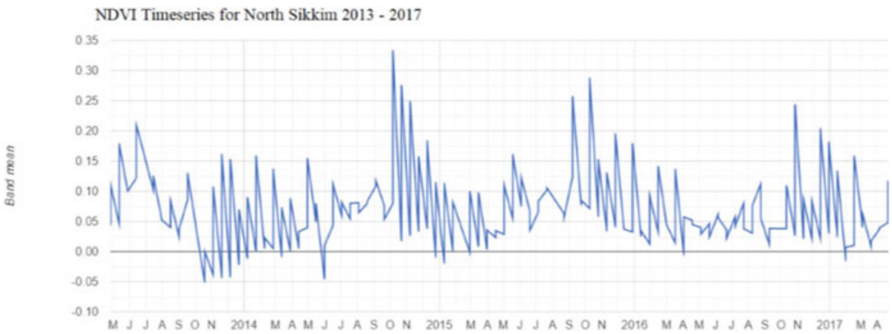


Fig. 9.5 NDVI trend analysis from 2013 to 2017

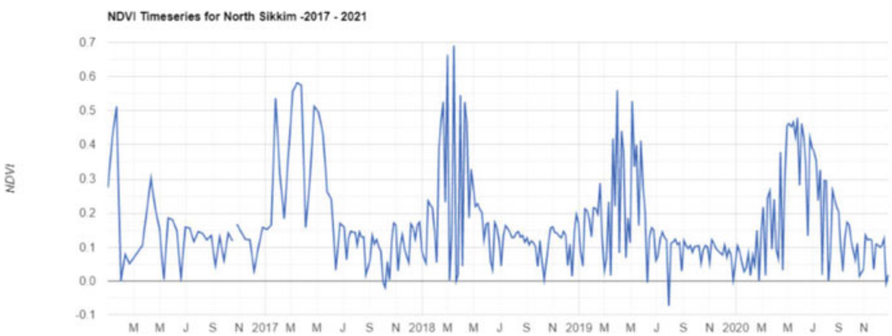


Fig. 9.6 NDVI trend analysis from 2017 to 2021

Summary statistics of the last 33 years show that maximum NDVI value 0.691 has been recorded in March 2018, whereas minimum NDVI value −0.732 has been recorded for March 2007. The mean NDVI values of the study area have been increased slightly from −0.191 to 0.164 (Table 9.6).

Five class categories of forest and their associated NDVI values have been identified for 1988, 2000, 2010, and 2021 which show that the NDVI value is highest for dense healthy vegetation and extremely lowest for barren land and snow-covered areas.

The highest threshold value of NDVI (0.6381) has been observed in 1988 (Fig. 9.7) in south and south-eastern part of the district (habitable area in Mangan subdivision) and adjoining villages of Chungthang subdivision (situated at the confluence of Lachen and Lachung river surrounded by dense forest cover and agricultural land). NDVI value is continuously decreasing northward with increasing altitude. The lowest NDVI value (−0.4828 in 1988) is observed in the north, north-west, north-east, and eastern part of the district. This sparsely vegetated region with

Table 9.6 Summary statistics of NDVI

Trend	Maximum value	Minimum value	Mean value	Standard deviation
1988–2013	0.138	−0.732	−0.191	0.204
2013–2017	0.333	−0.051	0.069	0.066
2017–2021	0.691	−0.074	0.164	0.135

Compiled by authors

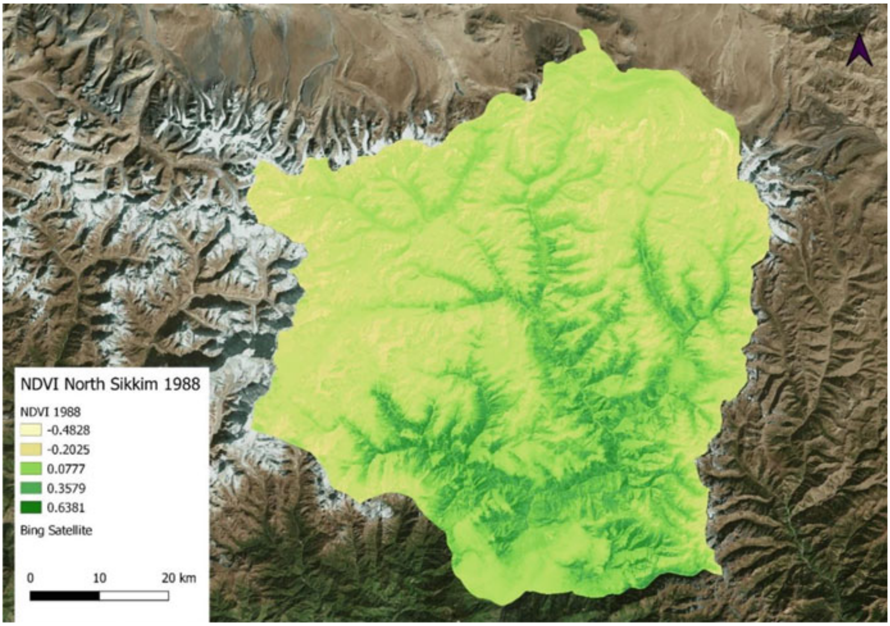


Fig. 9.7 NDVI classification of North Sikkim, 1988

snow cover, barren rocks, and water bodies shows a negative NDVI value. After 12 years (2000, Fig. 9.8), the highest NDVI value (+1) and lowest NDVI value (−0.1) both have been increased from 1988. In the year 2010 (Fig. 9.9), the highest NDVI value (0.6577) has decreased from 2000 but has increased slightly from 1988. On the other hand, the lowest NDVI value (−0.5) has increased since the last 22 years. Recent data shows that the highest NDVI value is 0.4915 and the lowest is −0.1251.

In all four images (Figs. 9.7–9.10), the lowest NDVI values are found on the less vegetated soil, snow-covered areas, and areas with a barren rock because the reflection from the soil is high and produces low values in the NIR band and high values in red bands; hence, the NDVI values are extremely low. Increasing trend of lowest NDVI value (or "browning") shows that less vegetated areas are increasing. Here the soil water availability is continuously decreasing with increasing altitude, rough topography, steep slope, low temperature, and low rainfall (stress by water deficit); the green vegetation tends to disappear which results in decreasing NDVI values from south to north. Thus, the NDVI method provides good results for varying vegetation densities and also for scattered vegetation from these multispectral remote sensing images (Gandhi et al. 2015). North Sikkim has experienced a fluctuating trend since the last 33 years. Increasing trend of NDVI (or "greening") which is observed in the south part of the district shows an increase of dense and healthy vegetation cover areas.

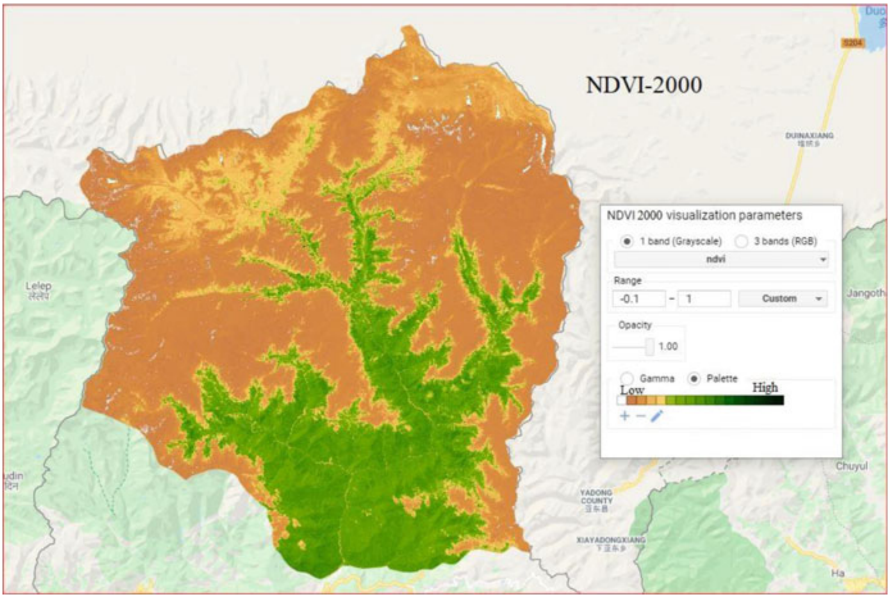


Fig. 9.8 NDVI classification of North Sikkim, 2000

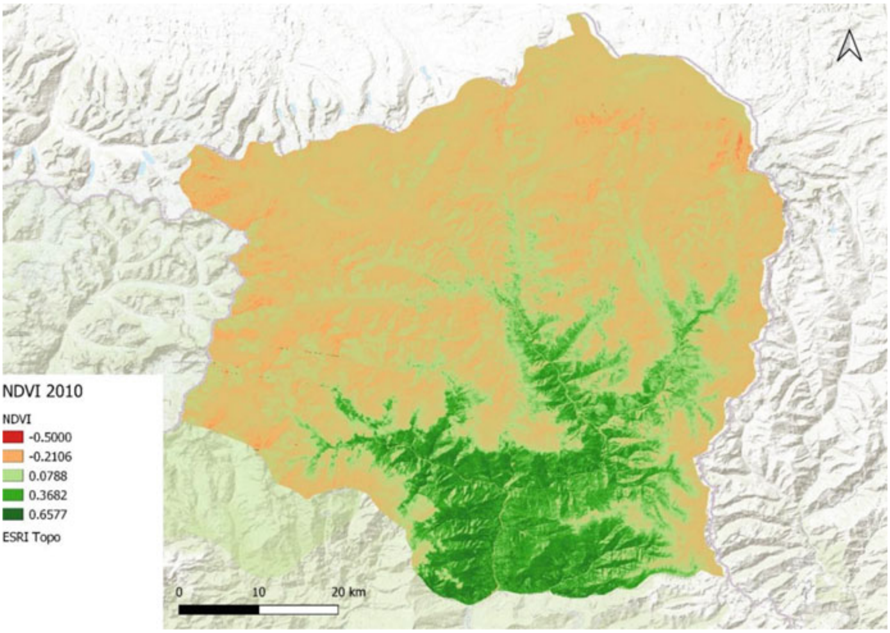


Fig. 9.9 NDVI classification of North Sikkim, 2010

9.6 Change Detection Analysis Based on Data Provided by Forest Survey of India and LULC Classification

For forest cover assessment in North Sikkim, 32 years' temporal satellite data have been used from FSI and depicted the changes in vegetation densities of all categories. RS-GIS technique has also been applied and land use and land cover maps of 1991, 2001, 2011, and 2021 have been used here to compare the FSI data.

As Sikkim is rich in biodiversity and holds a significant position in India in terms of forest resource, it is important to understand dense (all lands with tree canopy density of 70% and above) and open forest (all lands with tree canopy density of 10% to 40%) cover scenario.

Dense and open forest cover in Sikkim remain consistently higher (Figs. 9.11 and 9.12) than at the national level since the last 32 years.

Dense forest cover in India and Sikkim shows an increasing trend since the last 32 years but data for open forest cover shows a fluctuating scenario.

In district level analysis, forest density classes (dense, moderate, and open) in North Sikkim show a fluctuating scenario (Forest Survey of India, 2003–2019). The area (sq. km) under total forest cover shows a shallow decreasing trend from 2003 to 2019 and has become lowest in 2015 (772 sq.km). After 2015, the total forest cover area started to increase (Fig. 9.13). The area under dense forest cover shows an increasing trend since the last 16 years and has increased from 92 sq.km in 2003 to

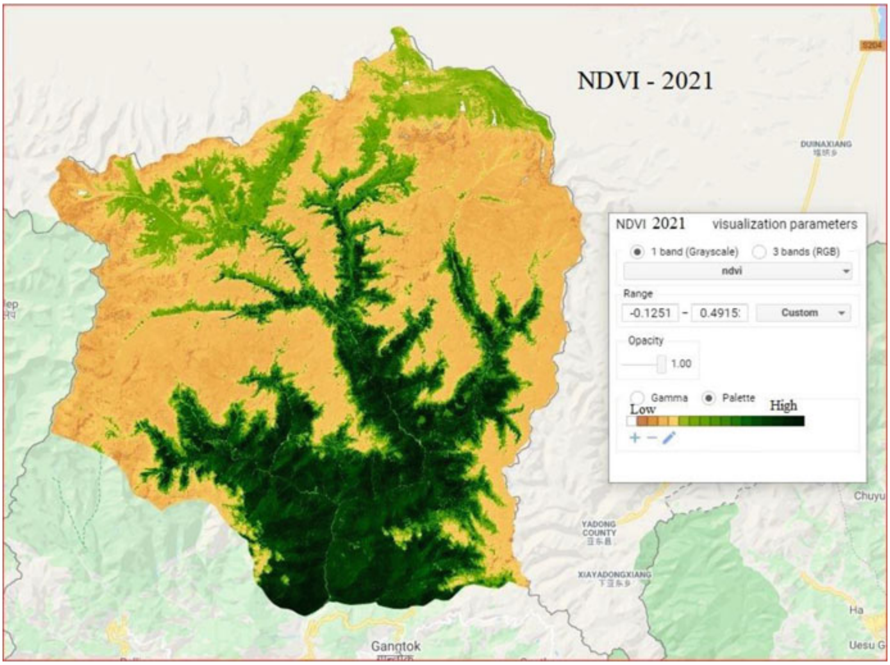


Fig. 9.10 NDVI classification of North Sikkim, 2021

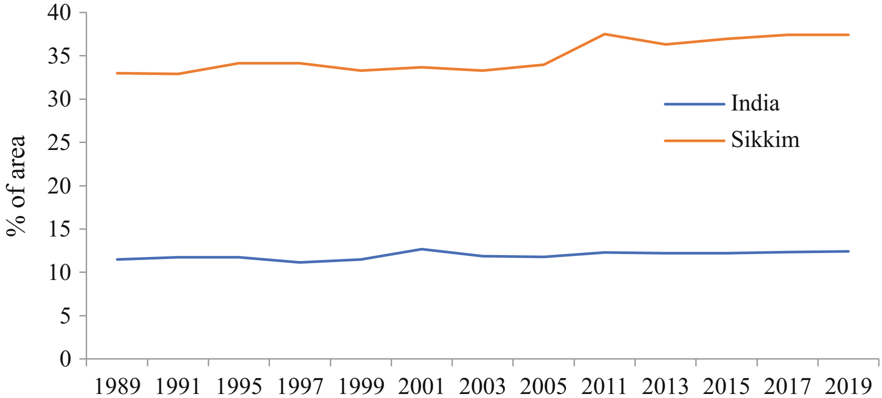


Fig. 9.11 Changing percentages of area under dense forest cover in India and Sikkim

410.61 sq.km in 2019 (Fig. 9.14). Dense forest areas in North Sikkim are mainly reserved forest areas. Figures 9.15 and 9.16 are showing the temporal changes of moderate and open forest areas. Both of the forest canopy density classes show a sharp declination trend since last 17 years. Moderate forest cover area has been decreased (Fig. 9.15) from 747 sq.km in 2003 to 586.81 sq.km in 2019. Open forest

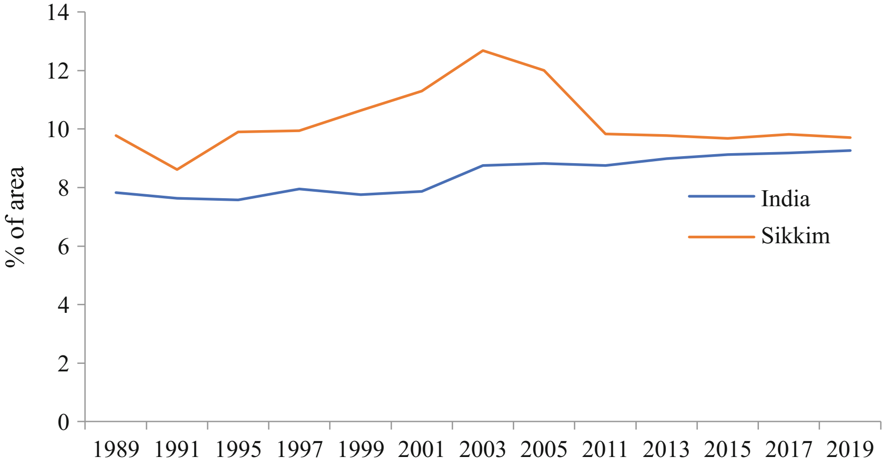


Fig. 9.12 Changing percentages of area under open forest cover in India and Sikkim. Source, ISFR, 1989–2019

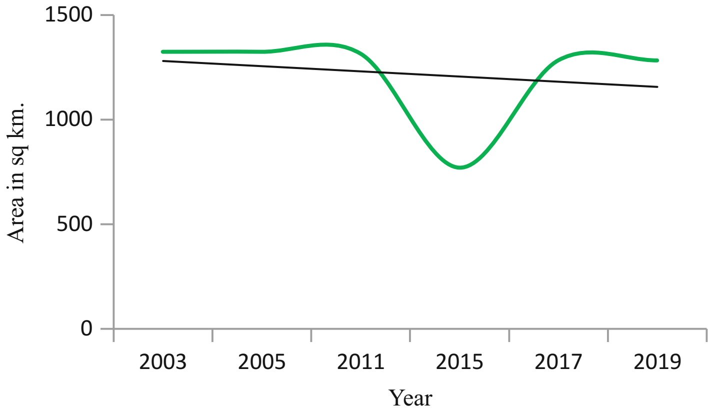


Fig. 9.13 Temporal changes in total forest cover area (sq. km) of North Sikkim

area on the other hand has been decreased (Fig. 9.16) from 487 sq.km in 2003 to 287.26 sq.km in 2019 (ISFR, 2003 to 2019).

From 1991 to 2021, four LULC maps have been prepared to study the temporal and spatial changes of land cover. Seven class categories have been identified for each to study the changes (Fig. 9.17, 9.18, 9.19 and 9.20) (Table 9.7).

After the analysis, it has been observed that most of the area is covered by open land followed by dense forest areas. Open land areas are inhabitable, barren, uncultivated, and snow-covered. There is no drastic change of areal coverage. From 1991 to 2011, dense forest cover area shows a decreasing trend, but after 2011, the forest area has increased up to 109.37 sq.km. Here, subsistence farming is

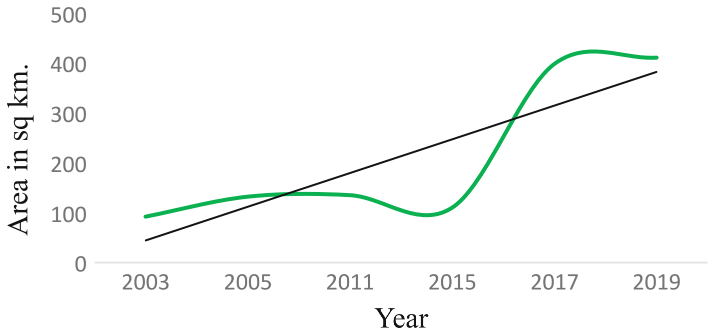


Fig. 9.14 Temporal changes in dense forest cover area (sq. km) of North Sikkim

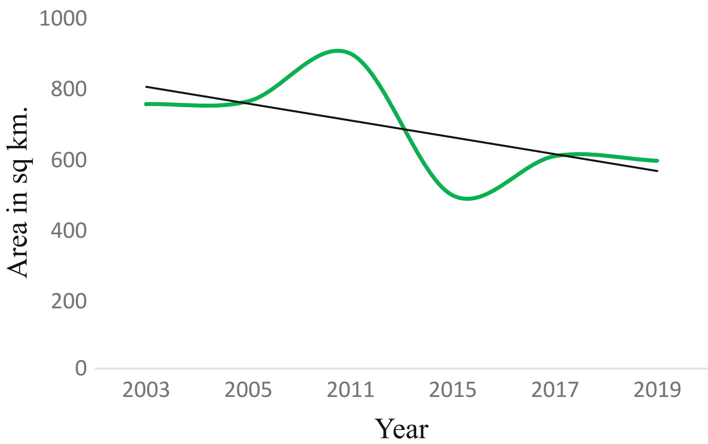


Fig. 9.15 Temporal changes in moderate forest cover area (sq. km) of North Sikkim.

based on man-cattle-forest relationship. Forest and grazing land are the source of fuelwood for cooking and heating and grass and shrub for fodder for livestock (Adhikari et al. 2004). Result shows that areas under agriculture and low vegetation land have been increased in the last 30 years which is a positive sign for rural economic development.

9.7 Community Perception

Local communities are highly involved in forest product collection and wood is the most significant forest product and have immense significance in daily life of local community. NFHS 4 shows that, schedule tribe (ST) tribe are mostly involved in forest product collection (Table. 9.8) than others. It is mainly because of the high

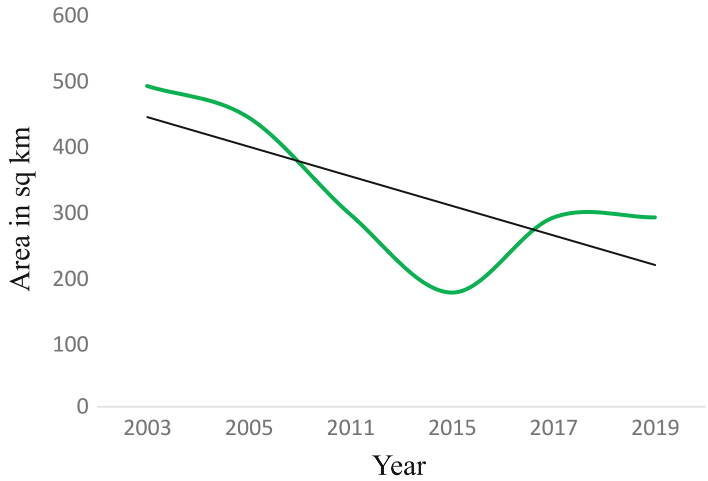


Fig. 9.16 Temporal changes in open forest cover area (sq. km) of North Sikkim

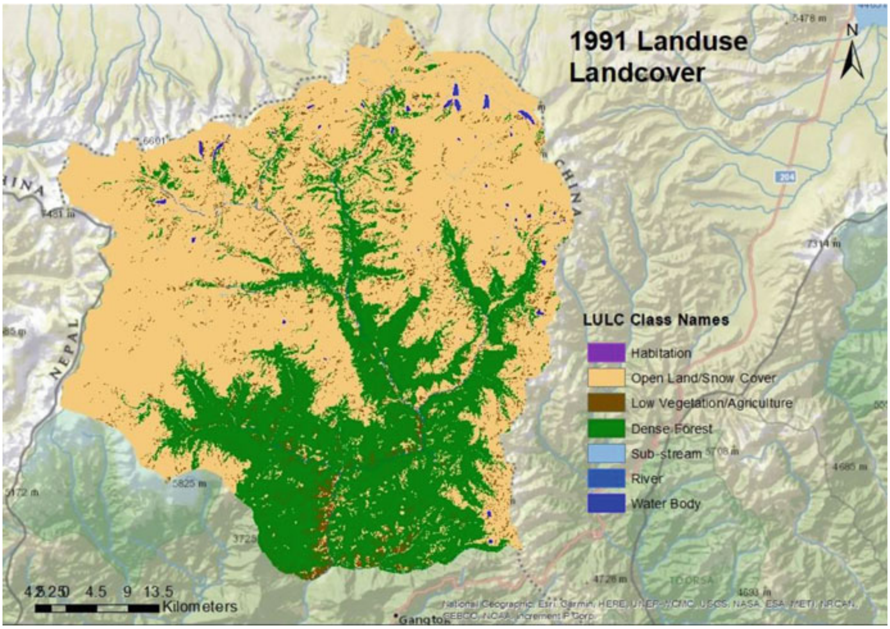


Fig. 9.17 Land use and land cover, 1991

concentration of ST (Lepcha, Bhutia and Limboo, Sikkim Human Development Report, 2014). From the field survey, it has been observed that a member in a forest management group has full choice where he or she can decide whether to participate in the forest management program or not. Despite active participation, some of the

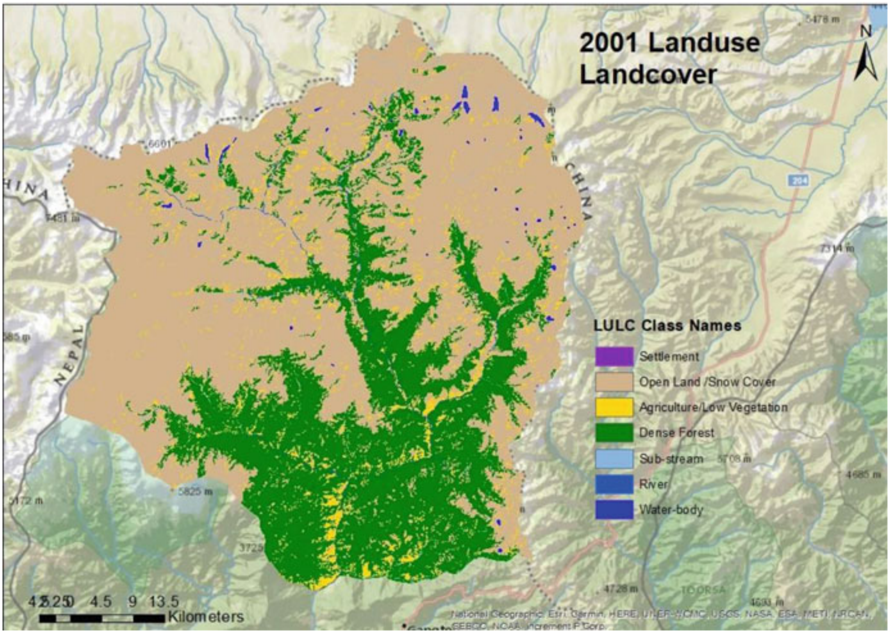


Fig. 9.18 Land use and land cover, 2001

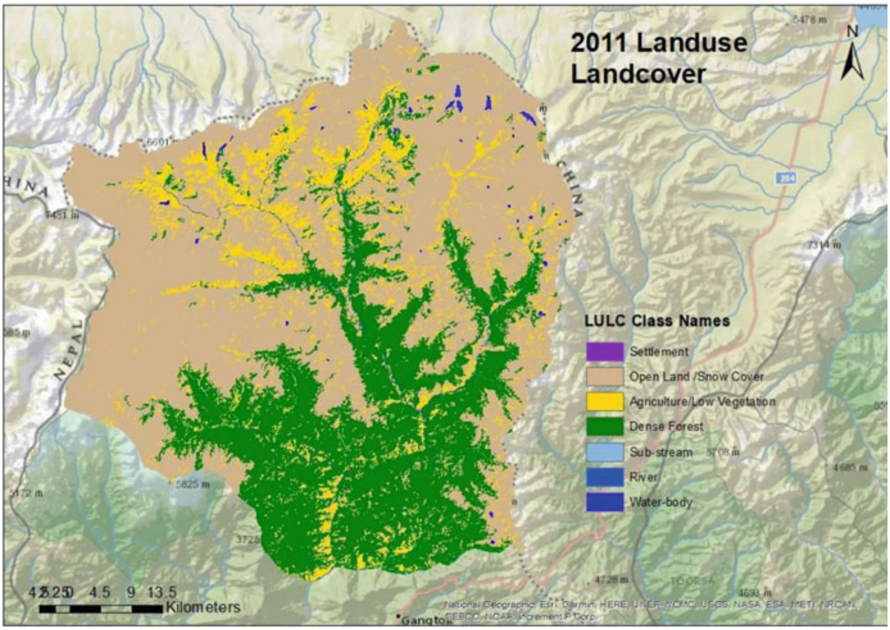


Fig. 9.19 Land use and land cover, 2011

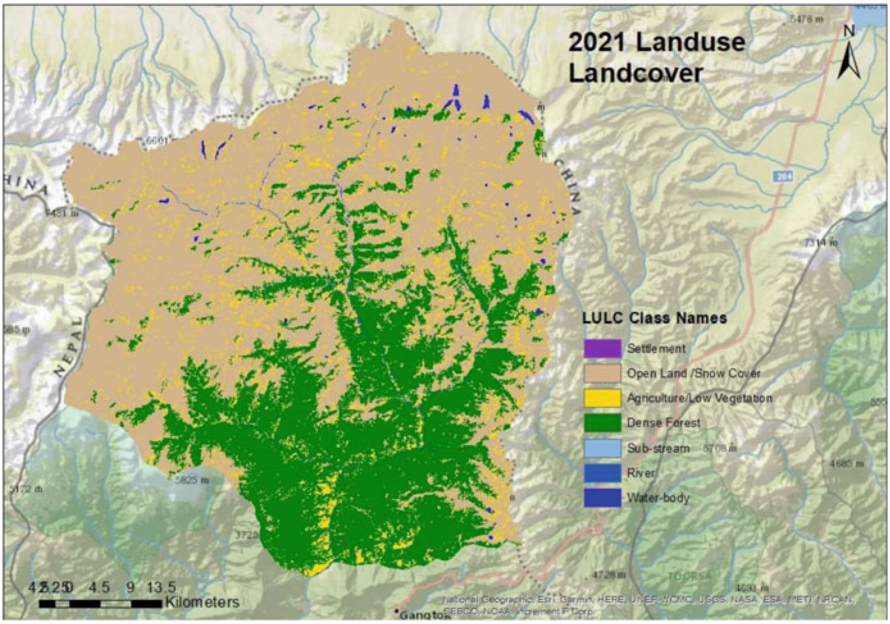


Fig. 9.20 Land use and land cover, 2021

Table 9.7 Changes of areas (sq. km) of LULC class categories from 1991 to 2021

Class name	1991	2001	2011	2021
Settlement/habitation	0.224	0.098	1.09	1.08
Open land/snow cover	2665.4	2667.73	2470.46	2510.34
Agriculture/low vegetation	184.54	191.94	442.51	311.92
Dense forest	1319.31	1308.04	1252.51	1361.88
Sub-stream	15.74	16.49	17.09	NA
River	15.06	15.91	16.25	15.06
Water body	12.85	12.87	12.91	12.85

Calculated by authors

Table 9.8 Caste-wise forest product collection in North Sikkim

Type of caste and tribe of household head	Wood	Straw/shrub/ grass	Agricultural crop	Animal dung
Schedule caste (SC)	51.46	2.51	3.66	9.99
Schedule tribe (ST)	71.54	0.80	0.82	0.94
Other backward class (OBC)	43.18	1.63	2.61	10.71
None of the above	15.15	1.42	1.89	5.17

Source: NFHS4

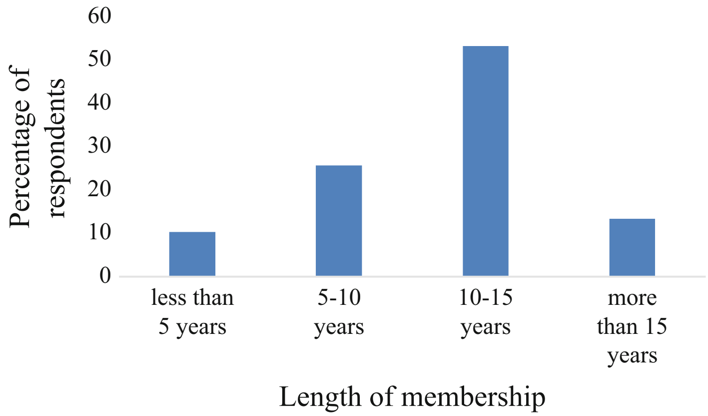


Fig. 9.21 Community perception on length of membership

local communities are continuously getting benefits and others reap the benefit without active participation. Hence, there exists inequality in participation. For the present study, few sets of variables have been identified through which the level of local community involvement can be perceived. The variables are as follows:

1. Length of membership in Joint Forest Management (JFM)/Economic Development Committee (EDC)
2. Availability of training facilities to local communities
3. Ecological and scientific knowledge of local communities
4. Representation of household members in JFM/EDC
5. The ability of local communities to participate in forest management programs
6. Educational attainment and level of involvement of the local community in JFMC/EDC

Length of membership has been identified as an important variable to identify the willingness of participation by the local community in JFM and EDC. It has been observed that 52% of the local community are members of JFM since the last 10–15 years where 25% are members for the last 5–10 years. Only 10% of the local community are members for a short duration, since the last 5 years (Fig. 9.21). Membership for long period enhances the decision-making abilities.

In the case of sustainable forest management, training programs for individuals or households enhance and expose to technical and strategic aspects and help to improve the household's attitude and knowledge. Requisite training program mainly involves the development of micro plan, capacity building activities, soil moisture conservation, and afforestation. Field survey shows that 56% of the local community are getting sufficient training facilities which have a positive influence on participation (Fig. 9.22). Kidegsho et al. (2007) have worked on this in Tanzania, Africa.

Ecological knowledge can also influence participation which is also associated with nature conservation and management process and issues. The State Forest

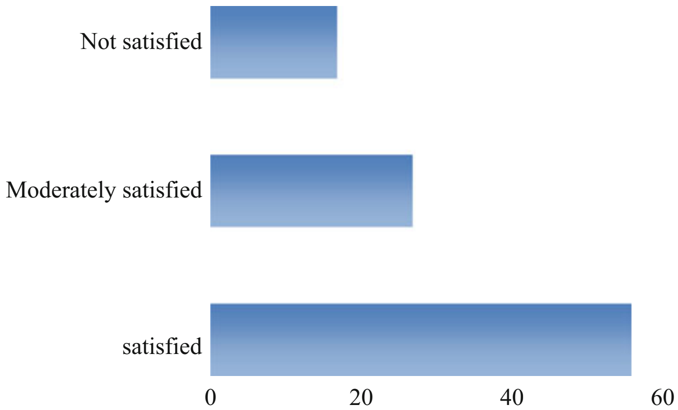


Fig. 9.22 Community perception on availability of training facilities. Source. Field survey, compiled by authors

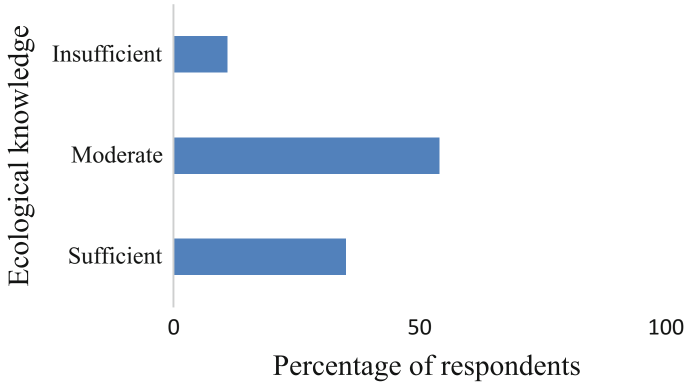


Fig. 9.23 Community perception on knowledge

Development Agency (SFDA) helps to transfer appropriate knowledge to the local community for sustainable forest management which combines traditional ecological knowledge and scientific knowledge. Perception survey to local communities shows that 52% of local communities have moderate traditional and scientific knowledge (Fig. 9.23). Being forest dwellers, they have a good cultural and ecological perception of the forest but they are still suffering from good scientific knowledge of management techniques.

Representation of household members in the JFM/EDC body also enhances the chances of community participation. More members from one household can fulfill the household's basic requirements and help to get employment opportunities in the lean period, and income derived from forest and agriculture and communities can act as wage labor. From the field survey, it has been observed that 61% of household

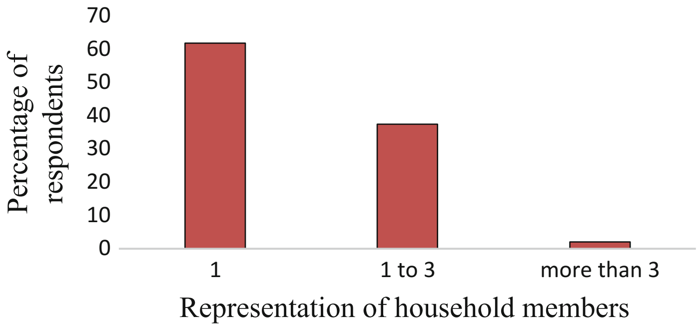


Fig. 9.24 Representation of household members in JFMC/EDC. Source. Field survey, compiled by author

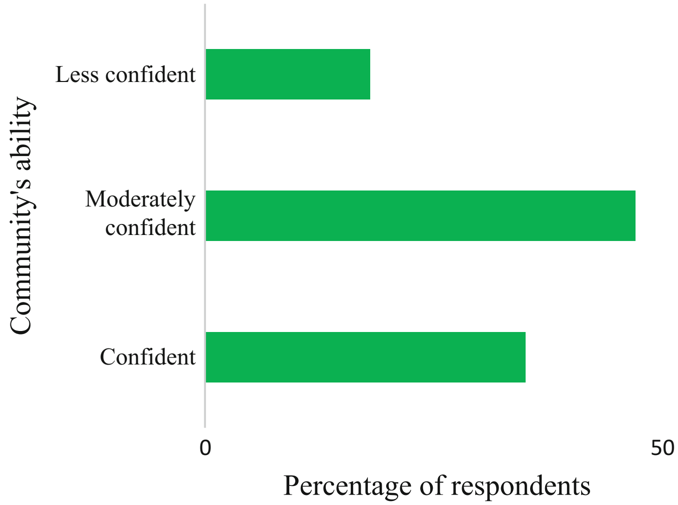


Fig. 9.25 Communities ability to participate in forest management programs

members have only one representative in JFMC/EDC and 37% of household members have one to three representatives in JFMC/EDC (Fig. 9.24).

Attitude is also an important variable of community behavior. It refers to the degree or level to which a community or a household has a favorable and unfavorable evaluation of the importance of community forest and whether or not their participation will be fruitful to achieve the goal of JFM/EDC. A positive attitude towards conservation positively affects the community's willingness to participate in forest management programs. From the field survey, it is evident that 35% of the respondents are confident in their abilities and they are more likely to participate in forest management program, whereas 18% of the respondents are less confident in their abilities (Fig. 9.25).

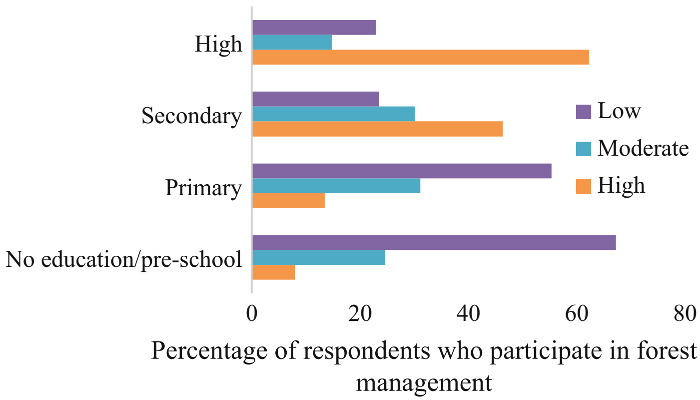


Fig. 9.26 Educational attainment and level of community participation

Educational attainment helps the capacity building of the local community and helps to change their attitude in forest management and participation scenario. Good knowledge and education help the local community to enhance their skills and help to generate and implement new ideas which ultimately affect decision-making and benefit-sharing from JFMC/EDC. Field survey (Fig. 9.26) shows that communities with low educational attainment have low participation rates and vice versa.

The level of participation in overall benefit remains as another important perception variable. Benefit has been classified as social and institutional benefit, ecological benefit, and economic benefit. Social and institutional benefit (De Vente et al. 2016) refers to the benefit acquired from conservation programs and getting benefits from conservation outcomes which enhance the positive attitude of local communities to participate in forest management programs. Ecological benefits enhance "individual attached value to forest ecosystem and their needs to protect forest" (Ayana et al. 2015). Ecological benefits include mitigation of floods, soil conservation, maintaining nutrient cycle, and providing forest resources.

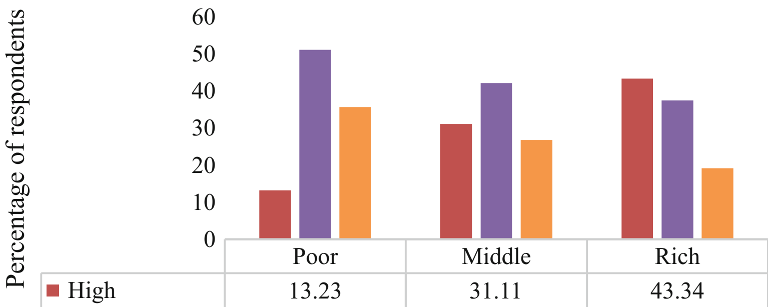
According to NFHS4, 56.04% of the rural population use fuelwood as their primary source of energy consumption. Communities rely on forests for fodder and leaf litter collection which are extensively used for livestock bedding, mulching, composting, and creating shades for crops. According to Sikkim Human Development Report 2014, the average forest product collection per household was 5475 kg per year, whereas leaf litter collection per household was 2920 kg. Caste-wise forest product collection and forest dependency vary. Being a forest dweller, indigenous communities, Lepcha, Bhutia, and Limboo (Risley 1928; Kharel and Bhutia 2013), are more likely to involve in forest product collection (Table 9.6) than others.

It is observed that among schedule tribe households, the percentage involved in fuelwood collection (71.54%) is high followed by schedule caste (51.46%). It is partly because ST concentration is also high in North Sikkim (78.20%, NFHS4) and partly because of the enactment of the "Scheduled Tribes and Other Traditional Forest Dwellers (Recognition of Forest Rights), Act, 2006." According to the Ministry of Tribal Affair, Government of India (2006), "this law empowers the forest dwellers and tribal communities to access and use the forest resource in the manner that they were traditionally accustomed and this act recognizes to protect, conserve, sustainably use and manage forest from unlawful evictions. Under this act, Gram Sabha is the highly empowered body which enables the tribal population to put forward their decision in terms of determination of local policies and schemes impacting them.”

9.8 Economic Profile of Local Communities and Participation in Forest Management Practices

From the field survey, it has been observed that decentralization of ownership from central to the local body has not always helped the local community; instead there exists an unequal scenario in terms of access and control over forest products, participation, and getting benefit from JFM/EDC.

For the field survey, three economic categories (depending on income) have been identified, i.e., poor (monthly average income less than 5000, little or no private land, marginal and seasonal workers, agricultural labors), middle (monthly average income between 5000 and 10,000, landholding between 2 and 6 hectare, mainly farmers), and rich (monthly average income more than 10,000, landholding more than 6 hectares, farmer and businessman). It is evident that community participation here has been controlled by the wealth condition of the communities. The wealthier group has higher participation scenario than the middle- and poor-income groups (Fig. 9.27). Among the rich income group, 43.34% of respondents are actively and highly involved in forest management activities, whereas in middle- and poor-income group this percentage is 31.11% and 13.23%, respectively. No participation



	Poor	Middle	Rich
High	13.23	31.11	43.34
low	51.11	42.12	37.5
no participation	35.66	26.77	19.16

Fig. 9.27 Level of community participation in terms of well-off categories

Table 9.9 Caste- and religion-wise wealth categories

Type of caste	Wealth quintile Poorest (lowest)	Poorer (second)	Middle	Richer (fourth)	Richest (highest)
Schedule caste	0.00	16.67	50.00	33.33	0
Schedule tribe	0.82	8.10	53.85	33.52	3.71
Other backward class	1.02	4.08	43.88	45.92	5.10
None of the above	0.00	5.81	30.23	52.33	11.63
Household head's religion					
Hindu	0.00	9.32	45.88	39.07	5.73
Muslim	0.00	0.00	33.03	66.67	0
Christian	1.96	17.65	50.98	27.45	1.96
Buddhist/Neo-Buddhist	1.01	6.05	52.77	35.80	4.37

Source, NFHS 4

rate, on the other hand, is high among the poor-income group (35.66%) and low among the high-income group (19.16%).

From the field survey it is evident that, poor households have extreme low participation rate in forest management and development activities than middle and high income groups. Poor households are less interested in participation and it is mainly because of lack of education and awareness. The study also corroborated with the findings of Adhikari et al. (2004).

NFHS 4 also provides measures of wealth index which is the composite measure of the household's cumulative living standards and a good indicator to portray the economic profile of local communities in the study area. It is composed of the household's living standards as well as assets (Rutstein and Johnson 2004). It is an indicator of the level of wealth that is half of the population in middle wealth quintile. For caste-wise and religion-wise wealth categories, over half of the population is in the middle quintile followed by the richer (fourth) wealth quintile (Table 9.9). The population that belongs to the poorest and poorer wealth quintile group has very little (1–2 hectare) or no access of private land and they are mainly marginal and contractual workers. Over half of the JFM/EDC members mainly belong to the middle to the rich wealthier group, and the participation of poor wealthier group is very low.

The household's wealth quintile depends on few socioeconomic variables. OLS regression analysis shows the association of wealth quintiles and socioeconomic-environmental indicators (Table 9.10).

Controlling for other factors, wealth quintile has a positive and significant association with the altitude of cluster households. Mainly *Lachungpa* (Buddhist) and *Lachenpa* (Buddhist) community (Bhasin 1989) live in high-altitude areas (Lachen and Lachung) who have large tract of land. Dominant and upper class Buddhist community are still enjoying feudal legacy and exercise special tribal

Table 9.10 OLS regression on socioeconomic status of local households

Altitude	0.0208***	0.0169***	0.0149***
	(0.00436)	(0.00442)	(0.00441)
Own livestock, herds, or farm animal	−0.0987***	−0.101***	−0.111***
	(0.0123)	(0.0121)	(0.0115)
Caste/tribe of household head	0.00517	−0.0271	−0.0229
	(0.0129)	(0.0153)	(0.0151)
Household has BPL card	−0.0495***	−0.0523***	−0.0431***
	(0.00962)	(0.00954)	(0.00927)
Female-headed household	−0.00228	−0.00326	−0.00845
	(0.0123)	(0.0123)	(0.0125)
Age of household head	0.00145	0.0000804	0.00305
	(0.00392)	(0.00398)	(0.00381)
Non-nuclear household	0.0316**	0.0307**	0.0156
	(0.0100)	(0.00994)	(0.00985)
Household head's religion Buddhist	0.0492***	0.0481***	
	(0.0123)	(0.0123)	
Highest educational level attainment	0.0161***		
	(0.00320)		
Constant	0.567***	0.578***	0.497***
	(0.0189)	(0.0192)	(0.0240)
Observation	934	934	904
R-sq	0.186	0.201	0.233
Standard errors in parentheses	0.180	0.194	0.225

Source. NFHS 4
*$p < 0.05$
**$p < 0.01$
***$p < 0.001$

power in administration, politics, and job sector, and they are designated as wealthier community here. Preferable geo-environment locations for Bhutia community are large hilly tract, cold climate, and snow bound areas (Subba 2011; District Gazetteer of Sikkim, 2013). A positive association between wealth and altitude mainly shows the cluster of household in high altitude areas inhabited by wealthier Bhutia community. Wealthier populations are mainly engaged with commercial agriculture (Large cardamom cultivation) along with homestay business and other government jobs. Hence, their livestock dependency is less than the poor households. Thus, regression result shows a negative association between wealth quintile and number of livestock. The share of BPL beneficiaries is 41.43%, but 58.57% of households are out of BPL card scheme, and indeed it has a negative and significant correlation with wealth quintile. Female-headed households, age of household head, and non-nuclear household have no significant association with wealth quintile. Educational attainment has a significant and positive association with wealth quintile which ultimately affects the community participation too. 40.79% of the population have secondary education, 28.16% have primary education, and 24.95% have preschool/no education. Only 5.78% of the population have high educational attainment. Secondary educational attainment is high among Buddhist (41.85%) and Hindu (40.50%). NFHS 4 data shows that unequal wealth distribution affects educational attainment and there exists a gap. Middle to rich households have higher educational attainment (secondary to high education) and vice versa. Wealthier households with high educational attainment intend to diversify their income and have more liquid assets. Poor households on the other hand, with lack of financial facilities, have lack of education enrolment too.

9.9 Discussion

Causes and dynamics of deforestation are multifaceted, which vary from place to place. 2010–2015 has marked a significant drop of moderate and open forest cover area. Different factors (Table 9.11) of deforestation have identified from the literature which play significant role in North Sikkim.

In North Sikkim, indigenous communities worship forests and perceive them as a bearer of local culture. For them, conservation of biodiversity and traditional cultural diversity are inseparable. The local communities value the use of traditional ecological knowledge in development activities (Sikkim Human Development Report 2014). However, forest resource has immense significance from environmental, culture, and social perspectives which ensures the wellbeing of indigenous communities.

Depletion of moderate and open forest has become a crucial concern for the forest-based indigenous communities. To preserve this natural resource and maintain its importance, the community forestry (CF) concept is continuously getting concern (Food and Agriculture Organization 2010). In developing countries where centralized forest ownership has failed to promote sustainable forest management, local communities are now more dependent on communally managed forest (Sunderlin 2006; Agarwal 2007; Maryudi et al. 2012; Schusser 2013; Baynes et al. 2015). In Sikkim, community forestry plays a crucial role to meet the need of local communities too (Adhikari 2005; Nagendra and Gokhale 2008; Chhetri et al. 2013).

Table 9.11 Drivers of deforestation

Physical drivers	Planned factors (infrastructure and development)	Unplanned factors (unauthorized, unsustainable not covered in official management plans)
Landslide	Hydroelectric power	Encroachment of forest land for agriculture and grazing
	Road construction	Shifting cultivation
	Irrigation projects	Unsustainable extraction of firewood and fodder
		Uncontrolled livestock grazing
		Unplanned felling

Compiled by author

9.9.1 Formation and Activities of JFMC/EDC

Reserved forest, *Khasmal*, and *Goucharan* forest have legal status and their ownership lies with the government. *Khasmal* is a part of the forest situated at the village fringe areas where villagers can enter and cut the forest products after taking formal permission from the forest department. *Goucharan* is a part of the village which is mainly used for grazing and villagers can cut the forest products. In Sikkim, following the 1988 National Forest Policy Resolution, the Forest Department of Sikkim was responsible for the constitution of Forest Protection Committees for management of reserved forest, *Khasmal*, and *Goucharan*, which was later renamed as JFMC and EDC. JFM notification was amended in 2001 and 2002. For JFM area selection, the notification stipulates that the district forest officer (DFO) has the full right to choose Gram Panchayat wards that fulfill two conditions: firstly, the ward should be vulnerable to serve biotic interference and damage to forest resources. Secondly, villagers are willing to offer their cooperation. After the selection of Gram Panchayat, the DFO then chooses a specific area considering the population size and requirement of forest products. Every family living in the Panchayat area could be a member of JFMC (ENVIS). As the forest area in North Sikkim is vast, community involvement is of utmost importance for forest management and protection. Without local community participation, the state cannot act effectively. In other parts of India, JFMC members plant trees in degraded state land and manage the forest in return for the benefit derived from selling non-timber forest products and harvesting of trees. In the case of Sikkim, the opportunity of JFM members to gain income from forest-related activities is limited because the commercial use of forest products is prohibited here. JFM can only be succeeded if the state government and local communities share the benefit jointly. In North Sikkim district, there exist 35 JFMC bodies situated in different elevation zones (Fig. 9.28).

9.9.2 Different Forms of Community Forestry

From field observation and literature survey (Chettri et al. 2015), significant community forestry management practices in North Sikkim have been identified (Table 9.12) and in Table 9.13, HCV potential sites in North Sikkim have been shown.

Kabi village in Kabi Tingda GPU in Mangan subdivision has its own sacred and historical significance. For centuries, indigenous Lepcha and Bhutia have been living (84.52% of schedule tribe population, Census of India, 2011) here. This highly dense forest area is protected by strong community conservation ethics and only dead and fallen trees are allowed to be collected. The state forest department fenced the surrounding area to protect this place from animal attack. Illegal action of forest product collection is completely prohibited here. Dominant plant species

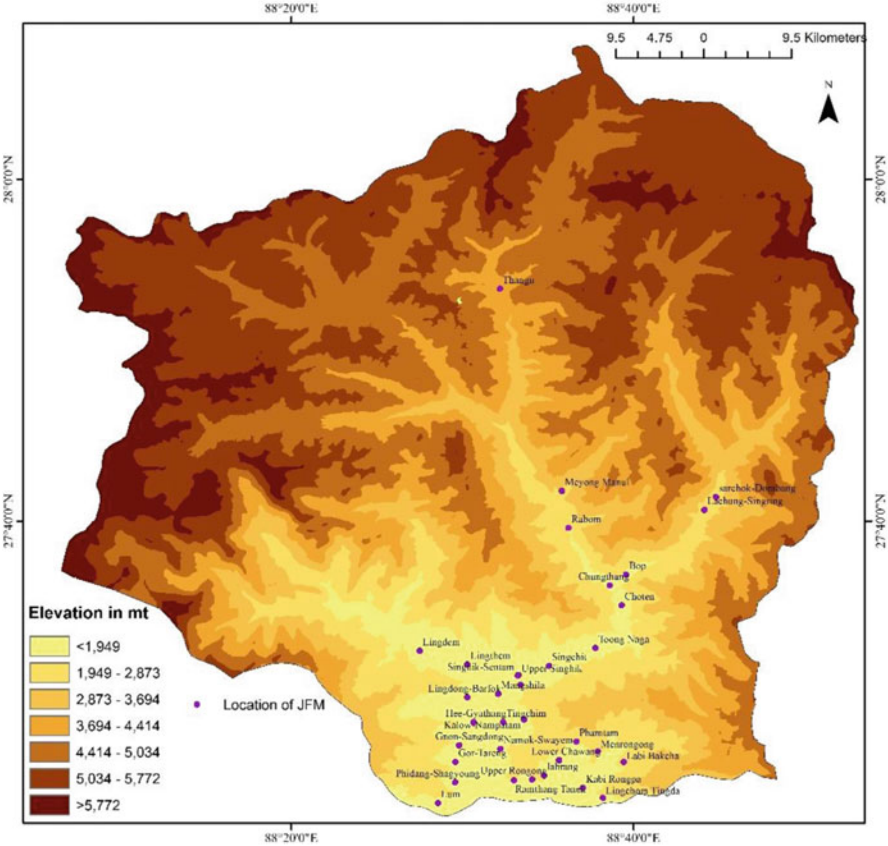


Fig. 9.28 Location of JFM in North Sikkim

Table 9.12 Community forest in North Sikkim and their community-level benefit

Forest type	Location	Coordinates	Elevation (mt)	Benefit to local community
Sacred Groves/ *Devrali* forest	Kabi-Lungchok village (Mangan subdivision)	27°24′23″N and 88°37′06″E	1501	Non-timber forest product (NTFP) and fuelwood
Community forest under *Dzumsa* system	Lachen and Lachung village (Chungthang subdivision)	Lachen – 27°43′00” N and 88°33′27″E Lachung −27°41′20”N and 88°44′34″E	Lachen – 2666 Lachung – 2617	Minor forest products
Community forest under *Bhamsey* system	Dzongu (Mangan subdivision)	27°30′35″ N and 88°26′15″E	2745	Agroforestry

Source: Compiled by author

Table 9.13 HCV potential sites in North Sikkim

HCV elements	Potential sites	Legal features	Significance	Responsible for protected areas
HCV1.1 – protected areas	Khangchendzonga National Park (altitude 1400–8585 mt and area 1784 sq. km)	Inscribed in IUCN in 2016 under criteria III, VI, VII, X World heritage sites (UNESCO's list of World Network of Biosphere Reserve) declared on 2018	1. Ecological, cultural, spiritual, and religious significance	1. Forest and Environment Department, Government of Sikkim 2. IUCN
Threats – low (climate change, trekking)				
HCV1.1 – protected areas	Shingba Rhododendron Sanctuary (3048–4875 mt and area is 43 sq. km. Biogeographic zone trans-Himalaya)	1.Inscribed in IUCN 2. IBA Cite Code-IN-SK-11 3. IBA criteria A1 (threatened species), A2 (endemic bird area 130; Eastern Himalaya), A3 (Biome-5, Eurasian High Montane; Biome-7, Sub-Himalayan Temperate Forest; Biome-8, Shino-Himalayan Sub-tropical Forest)	1. Home of endemic *Rhododendron niveum* (state tree) 2. Home of alpine herbs, meadows, and scrubs 3.The globally threatened wood snipe *Gallinago nemoricola* is occasionally seen 4. Home of wild medicinal plants and plants with religious significance	Ministry of Environment and Forest, Government of India
Threat – low (military use, trekking, collection of junipers and *Rhododendron* for incense)				
HCV3 – forest areas that are in or contain rare, threatened, or endangered species	Eastern Himalayan Broadleaf Forest	Under WWF 200 global ecoregion (IM0401, under Indo-Malayan ecoregion category)	1. Rich in endemic and near endemic species (flora and fauna)	Ministry of Environment and Forest, Government of India, WWF, and International Centre for Integrated Mountain Development (ICIMOD)
Priority conservation action – long-term and short-term conservation actions have been taken including strict control against illegal hunting, habitat restoration, ban on grazing, conducting biological inventories				
HCV5 – forest areas fundamental to meeting the	*Khasmal* forests (any forest land settled and set aside by	First demarcated during 1952 cadastral survey and after that	1.Accessible for local communities 2.Provide basic	Forest and Environment Department (Government of Sikkim),

(continued)

Table 9.13 (continued)

HCV elements	Potential sites	Legal features	Significance	Responsible for protected areas
basic needs of local communities	government for meeting the bonafide domestic need of timber, firewood, and fodder of the adjoining villages (Forest and Environment department, Sikkim), i.e., Yaksheythang Khasmal forests in Lachung Dzumsa GPU	specified in the Sikkim Forest and Water Courses Act, 2007	needs (fuel, food, medicine, and construction materials) to local communities 3. Local community depends on Khasmal forest throughout the year	Gram Panchayat, Dzumsa system in Lachen and Lachung area (local people's organization) JFM and EDC, local community
Threat – (moderate) – illegal encroachment and overutilization of forest products (anthropogenic cause), forest fire (environmental hazard)				
HCV6 – forest areas critical to local communities' cultural identity	Sacred groves/ *Devrali* forest (Kabi-Lungchok village in Mangan subdivision) 3. Community forest in *Bhamsey* system (Dzongu in Mangan subdivision)	Identified and demarcated by the State Forest Department mainly in post-merger period (1975)	1.Conserved by local communities for belief in forest deity (spiritual significance) 2. Protection of natural water source 3.Considered as a sacred space where ancestors of local communities have been buried 4. Considered them as religious space (*devithan*)	State Forest Department and Gram Panchayat

Source: Compiled by author

include *Engelhardtia spicata*, *Castanopsis tribuloides*, *Daphniphyllum himalayense*, and *Eurya acuminata*.

Dzumsa is a traditional local self-government system that exists in Lachung and Lachen valley in North Sikkim. Despite the introduction of Panchayati Raj Institution (PRI) in Sikkim in 1993, this traditional political framework is continuing in these two villages because PRI in Sikkim has given legitimacy for the continuation of this non-Panchayati Raj tribal council. Major economic decisions including land cultivation and distribution levied and tax revenue from government, grazing activities, and seasonal migration are taken by the *Dzumsa* system. *Dzumsa* regulates the collection of forest products and sowing and harvesting of crops. The local community participates in forest management programs with the help of *Dzumsa* and the Village Development Committee (Chettri et al. 2015). Forest products are an intangible part of their culture and economy. To perform religious functions, firewood is usually collected by the local community and found to be stored in the *Dzumsa* meeting hall. *Dzumsa* is maintaining a close-knit relationship with the state forest department where the state forest department supplies plant species.

Bhamsey system is practiced in Dzongu where the local community mainly practiced farming as a predominant economic activity. They cultivate rice, millet, and vegetables as subsistence crops and large cardamom as commercial crops. Slash and burn cultivation (locally called *jhum* cultivation) is highly practiced here (Ramakrishnan 1998) where private farmland and open forest are continuously cleared by the local community.

9.10 HCV as a Prospective Conservation Strategy

To protect and conserve the pristine environment, conservation ethics of local communities and sustainable development ethics of local government have resulted in conservation of this unique biological resource. For local community, forest and natural resources are a matter of worship and it has a religious connotation. Government and non-government organizations are working at the grassroots level to maintain and preserve the pristine forests. Forest certification scheme has been developed as a guideline for SFM in the recent past. According to WWF (2002), the forest certification scheme is an important initiative and mechanism for forest monitoring, change detection, and labeling of timber and non-timber forest products (NTFPs) where the significance of the forest can be judged against a proper standard.

This chapter tries to imply HCV model as a part of forest conservation and preservation of local values. Six areas have been identified for a full set of HCVF:

1. HCV1 – Globally, regionally, and nationally significant concentration of biodiversity values

   HCV1.1 protected areas, *HCV1.2* threatened and endangered species, *HCV1.3* endemic species, *HCV1.4* critical temporal use
2. HCV2 – Globally, regionally, and nationally significant large landscape-level forest
3. HCV3 – Forest areas that are in or contain rare, threatened, and endangered ecosystem
4. HCV4 – Forest areas that provided basic services of nature in critical situations (e.g., watershed protection, erosion control)

   HCV4.1 forest critical to water catchment, *HCV4.2* forest critical to erosion control, *HCV4.3* forest provides a barrier to destructive fire

5. HCV5 – Forest areas fundamental to meeting the basic needs of local communities
6. HCV6 – Forest areas critical to local communities' traditional cultural identity

Though the HCVF framework has started to be implemented in different countries across the globe, there is no such HCV implementation yet in India. At the subnational level, it could also be implemented especially in the Sikkim-Himalayan region.

The implication of HCV in the case of forest conservation and management in North Sikkim is important from different perspectives:

(a) Conservation of rare and valuable species and the areas which are biologically significant
(b) Protection of local communities, villages, agricultural land from flood, landslide, and soil erosion
(c) Conservation of forest for forest-based local and indigenous communities
(d) Conservation of the areas with heritage and cultural significance

From the literature survey, obtaining information from government websites and from field surveys, this research seeks to identify few HCVF potential sites.

9.11 Conclusion

Assessing forest cover dynamics in areas like North Sikkim has great environmental and socioeconomic implication. Due to remoteness and strict government regulation, degradation of dense forest cover is almost negligible here. On the other hand, moderate and open forest cover are changing which is an alert for Sikkim's biodiversity and livelihood for local community. This chapter depicts the different aspects of effective community participation where community's wellbeing also controls their participation. Decentralized forest management programs and the establishment of JFMC/EDC have expanded the forest management activities and encourage the local community to preserve this pristine environment. This research tries to establish HCV model as a potential management strategy for the forest which have global, national, and regional significance. This research has few limitations. Remote and less accessible village location and poor language communication with villagers restrict smooth survey. On the other hand, frequent landslides disrupt transportation and affect survey. Implementation of HCV model will develop management strategies more comprehensively. Overall this research has potentiality for stakeholders, government policymakers, investors, donors, forest managers, and organizations.

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Chapter 10
Carbon Stock Assessment in Sub-humid Tropical Forest Stands of the Eastern Himalayan Foothills

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Abstract Assessment of carbon storage potential of a forest is difficult due to a lack of information on biomass partitioning and allocation in different species. For most of the species only above-ground biomass potential is known, but to have a picture of carbon storage potential of species, the below-ground biomass is equally important. With this in view a study was conducted at Jaldapara National Park located in the foothills of Eastern Himalayas to analyze the tree dominance, biomass production, and biomass carbon stocks of five forest stands of *Tectona grandis* dominant stands (TGDS), *Shorea robusta* dominant stands (SRDS), *Michelia champaca* dominant stands (MCDS), *Lagerstroemia speciosa* dominant stands, and miscellaneous stands (MS). Trees contributed 87.3–96.5% of the total biomass in the studied stand and the rest by shrubs, herbs, and litters, while AGB contributed 70.5–84.7%. Stratified random nested quadrate sampling method was adopted in this study. The ecosystem carbon stock varied significantly among the stands in the range of 145.8–454.3 Mg C ha^{-1}. Consequent of significantly higher species richness, population, and basal area, the MS was estimated with significantly higher vegetation biomass and soil organic carbon stock and thus significantly also had higher ecosystem carbon stock than the species dominant stands. The MS was quantified with 2.64–3.12 times higher ecosystem carbon stock than the species dominant stands. *Tectona grandis*, *Shorea robusta*, *Michelia champaca*, and *Lagerstroemia speciosa* are popular timber species with high commercial demand. Forests are now known as net emitter and need sustained conservation efforts. The forests of the region can be relieved from commercial pressure through developing plantations of these high-value timber species involving local population. It is advocated to manage these plantations as semi-natural forest with heterogeneous regional vegetation allowing minimum or no

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disturbances that can fulfill commercial, social, and ecological needs. Success of such plantation programs needs policy support with adequate compensation and incentives. These plantations in non-forested landscapes will supplement the forest in terms of conserving and enhancing the terrestrial carbon sink of the region. However, systematic and holistic research is required to understand the regional patterns, fluxes, magnitude, and driving mechanisms of terrestrial carbon sinks and sources for efficient policy support and management decisions. Meanwhile, with the regional tree species identified, silvicultural actions and policy framework can be formulated to initiate carbon farming with the identified tree species in the region.

Keywords Forest stand · Biomass · Carbon stock · Climate change · Jaldapara National Park

10.1 Introduction

The rapid accumulation of carbon dioxide and other greenhouse gases in the atmosphere as a result of fossil fuel use for energy production, industrialization, deforestation, and forest degradation has accelerated the rate of climate change (Hounghton et al. 1998). Forests are both source and sink of carbon (Haripriya 2003; Usuga et al. 2010). Forests store carbon in their biomass and soil through photosynthesis and emit it through respiration and anthropogenic disturbances. Converting forest lands to other land uses had contributed up to 20% of the global greenhouse gas emissions. Carbon stored and emitted by forests needs to be quantified for formulating viable and efficient policy and management actions toward climate smart sustainable development (Shukla 2010). Carbon regulation is the most important management action for climate smart sustainable goals of the twenty-first century. One of the main focus areas for carbon management is enhanced carbon uptake and storage by plants and forests. Improving the sink and decreasing net emission is possible by improved climate smart land management practices. Assessing carbon sequestration of forest will aid in identifying the best land management option(s) which will not only improve the carbon storage capacity of the forest but also will reduce emission from it (Bhadwal and Singh 2002; Ahmad and Nizami 2014). Unfortunately, this task is laced with difficulties as species-specific biomass partitioning is still less understood with information mostly on aerial allocation of biomass by the species while ignoring the below-ground allocation (Chauhan et al. 2009).

India is endowed with diverse forest types whose structural and functional attributes are yet to be properly understood, consequent of which the forests are still not ranked based on their sink capabilities (Pande 2001). Studies on the floristic and quantitative aspect of forest have already been initiated by workers (Shukla et al. 2013, 2014) but the work on standing stock of biomass of different stand in the forest is yet to be started. Analysis of forest structure and function for proper understanding of source and sink potential will help in its sustainable development to mitigate climate change. So, an attempt was made in this chapter to understand the tree species-specific sink potential of different forest stands. Quantifying the sink capacity of the forest stands and the constituent tree species will be helpful for developing sustainable management strategies to regulate the forest as a viable sink while restricting net emission. The present study was therefore conducted to estimate (i) important value index of species in the selected forest stands of *Tectona grandis*, *Shorea robusta*, *Michelia champaca*, *Lagerstroemia speciosa*, and mixed forest species, (ii) tree density in each stand, (iii) basal area, and finally (iv) standing biomass and carbon estimates of different stands in the forest.

10.2 Materials and Methods

10.2.1 Site Description and Sampling

The Jaldapara National Park (JNP) in Terai region of eastern Himalayan foothills was the study site of the present study (Fig. 10.1). The region is also included in the IUCN listed Himalayan Biodiversity Hotspot (Myers et al. 2000). Prominent vegetation of the park is savannah including giant grasses. Mixed deciduous, wet monsoon type, tropical moist deciduous, tropical semi-evergreen, and riverine types of vegetation are also common in the park (Champion and Seth 1968). The geographical location of the park was between 25° 58′-27° 45′ N latitude and 89°

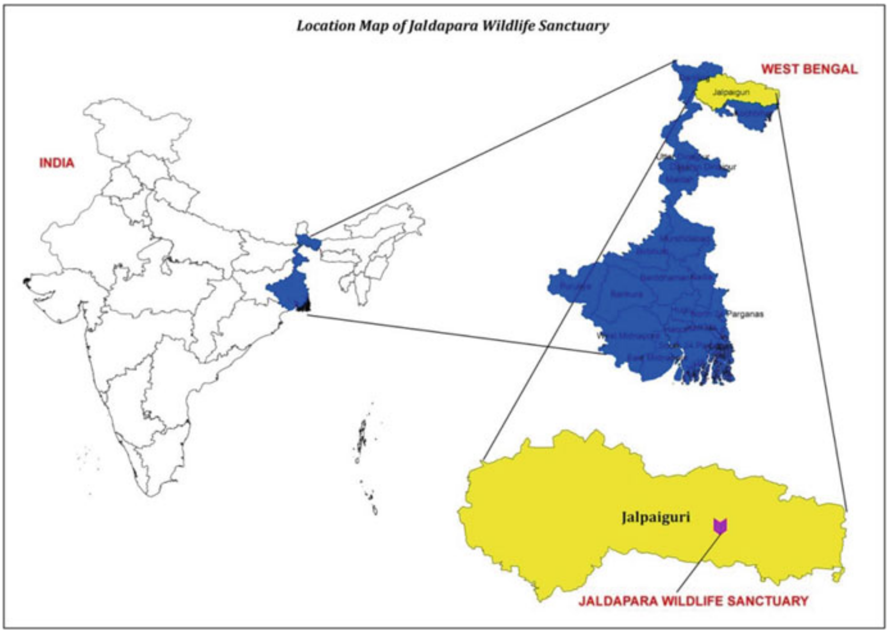

Fig. 10.1 Map of the study area

08′-89° 55′ E longitudes at an average altitude of 47 m above mean sea level (GPS Germin-72). The climate is subtropical with moderate temperature (7.5–34 °C) and heavy rainfall (annual average of 250–300 cm) affected by south-west monsoon, the bulk of which precipitated between June and August.

We selected the forest stands following Prakash (1986) based on the composition of dominant tree species in the respective stands as pure (≥75%), mainly single species dominant (50–75%), mixed (25–50%), and miscellaneous (<25%) stands. Based on this classification of forest stands, we found single species dominant and miscellaneous stands prevalent in our study site. The single species dominant stands were *Tectona grandis*, *Shorea robusta*, *Michelia champaca*, and *Lagerstroemia speciosa*. We marked 15 quadrates of 20 m × 20 m size in each stand adopting stratified random nested quadrate sampling technique to collect soil and biomass data. Two smaller quadrates of size 5 m × 5 m were laid at diagonal corners of the main quadrate for shrubs and five smallest quadrates of size 1 m × 1 m for herbs (four at each corner and one at the center of the main quadrate). All the trees were counted in the main quadrate, while five shrubs and entire herbs from their respective quadrates were sampled. We used Dutch augur to collect composite soil samples once at 0–20, 20–40, and 40–60 cm depth separately. The entire deposited litter debris were cleared and swept away from the smallest quadrates in each stand.

10.2.2 Methods Used

Density (D): Density is the numerical strength of a species reflecting dominance and rarity of that particular species and is expressed as the number of individuals in a unit area. We considered only the tree density for this study.

Basal area: Basal area (BA) was estimated using the diameter of the selected trees at breast height (1.37 m) with the given below formula.

$$BA = \pi r^2$$

where $\pi = 3.142$ and r is radius

Tree diameter and height: The diameter of the tree was measured with the help of a tree caliper, while the height was measured with a Ravi's altimeter.

Importance Value Index (IVI): This is an index which indicates dominance of species with respect to relative count, relative frequency of occurrence, and relative dominance measured as basal area of species. IVI was estimated as summation of relative density, relative frequency, and relative basal area.

Biomass and carbon estimation: We employed nondestructive method to estimate the biomass of the trees in the stands. We selected the trees with dbh $\geq$ 30 cm in the stands for biomass quantification (Knight 1963) and adopted Mishra (1968) to estimate density. Volume equations of Forest Research Institute (FRI) and Forest Survey of India (FSI) were used to quantify the Growing Stock Volume (GSV) of the tree species separately found in the stands. The estimated GSV was then multiplied with biomass expansion factor (BEF) to obtain above-ground biomass density (AGBD) (Brown et al. 1999). Different BEFs were used (1.0, 0.81, 0.95, and 1.68) based on the growing stock density (G) of the species ($\geq$200, >100, 10–100, and < 10 m^3 ha^{-1}, respectively). The below-ground biomass density (BGBD) of a tree species was estimated adopting Cairns et al. (1997). In case when the volume equation was not available for a species, the biomass density of the species was quantified following Negi et al. (1998). The total biomass density (TBD) of the tree species was the summation of its above- and below-ground biomass densities. The biomass of the five uprooted shrubs (selected randomly) and entire herbs from each of their respective quadrates was estimated by weighing them separately as roots and aerial parts. Prior permission from the State Forest Department was obtained for this destructive estimation. IPCC considers biomass carbon as half of the biomass (IPCC 2000).

10.2.3 Statistical Analysis

We adopted analytical statistics with regression, correlation, and one-way ANOVA in SPSS version 17 (VSN International, Oxford, UK).

10.3 Results and Discussion

10.3.1 Tree Species Richness

Dominance of a particular species in the studied forest stands at the study site was due to the selection of that species for establishment (Shukla 2010; Shukla et al. 2013, 2014, 2017; Rai et al. 2021). Tree species richness, IVI, density, and basal area of the different stands are given in Tables 10.1-10.5. The *Lagerstroemia speciosa* dominated stand (LSDS) was represented by 12 species, 10 families, and 11 genera (Table 10.1). The other tree species growing in this stand with the dominant species are thus termed as associated or dominated species.

As the stands were identified on the basis of species dominance, obviously the dominating species was estimated with the highest density (individual ha^{-1}), basal area (m^2 ha^{-1}), and IVI. The IVI, density, and basal area of *Lagerstroemia speciosa* estimated were 433.3, 136 tree ha^{-1}, and 20.44 m^2 ha^{-1}, respectively. The other important tree species based on their IVI are Schima wallichii, *Terminalia crenulata*, *Tectona grandis* and *Michelia champaca*. Similarly, the *Michelia champaca* dominated stand (MCDS) was represented by ten tree species, eight families, and nine genera (Table 10.2). The IVI, density, and basal area of the dominant *Michelia champaca* in the stand estimated were 418.7, 118.8 trees ha^{-1}, and 22.56 m^2 ha^{-1}, respectively. The other important species in descending order or the associated

Table 10.1 Tree species diversity, density, and basal area of the LSDS

Sl. no.	Tree species	Family	D	BA	IVI
1	*Dillenia indica* L.	Dilleniaceae	6.3	0.38	36.0
2	*Duabanga grandiflora* (Roxb. ex DC.) Walpers	Lythraceae	2.5	0.33	18.7
3	*Lagerstroemia parviflora* Roxb.	Lythraceae	5.0	0.35	29.5
4	*Lagerstroemia speciosa* (L.) Pers.	Lythraceae	136.3	20.44	433.3
5	*Michelia champaca* L.	Magnoliaceae	2.5	0.43	18.7
6	*Phoebe lanceolata*	Lauraceae	2.5	0.18	18.7
7	*Schima wallichii* (DC.) Korth.	Theaceae	6.3	0.56	35.0
8	*Shorea robusta* Roth.	Dipterocarpaceae	2.5	0.18	18.7
9	*Syzygium cumini* (L) Skeels	Myrtaceae	3.8	0.49	24.5
10	*Tectona grandis* L.f.	Verbenaceae	6.3	1.13	34.1
11	*Terminalia crenulata* (Heyne) Roth	Combretaceae	10.0	7.00	47.4
12	*Toona ciliata* M. Roem.	Meliaceae	2.5	0.20	18.7

LSDS: *Lagerstroemia speciosa* dominated stand, D: density (individual ha^{-1}), BA: basal area (m^2 ha^{-1}), IVI: important value index

Table 10.2 Tree species diversity, density, and basal area of the MCDS

Sl. no.	Tree species	Family	D	BA	IVI
1	*Alstonia scholaris* (L.) R.Br.	Apocynaceae	1.3	0.18	14.4
2	*Bombax ceiba L.*	Malvaceae	1.3	0.25	14.4
3	*Duabanga grandiflora* (Roxb. ex DC.) Walpers	Lythraceae	2.5	0.20	24.1
4	*Ficus neriifolia* Sm.	Moraceae	2.5	0.18	22.0
5	*Lagerstroemia parviflora* Roxb.	Lythraceae	8.8	1.31	50.6
6	*Lagerstroemia speciosa* (L.) Pers.	Lythraceae	6.3	0.50	40.7
7	*Michelia champaca* L.	Magnoliaceae	118.8	22.6	418.7
8	*Schima wallichii* (DC.) Korth.	Theaceae	7.5	0.38	46.1
9	*Tectona grandis* L.f.	Verbenaceae	11.3	1.13	59.6
10	*Toona ciliata* M. Roem.	Meliaceae	3.8	0.15	28.2
Total			**163.8**	**26.83**	

MCDS: *Michelia champaca* dominated stand (MDS), D: density (individual ha^{-1}), BA: basal area (m^2 ha^{-1}), IVI: important value index

species were *Tectona grandis, Lagerstroemia parviflora*, *Schima wallichii*, and *Lagerstroemia speciosa*.

The tree diversity, density, and basal area of *Shorea robusta* dominated stand (SRDS) are given in Table 10.3. The stand was listed with 12 species represented by 10 families and 11 genera. The dominant species *Shorea robusta* was estimated with the highest IVI, density, and basal area values of 465.3, 161.3 trees ha^{-1}, and 22.58 m^2 ha^{-1}, respectively. The other important tree species according to the stand descending chronological order of their IVI were *Schima wallichii*, *Terminalia*

Table 10.3 Tree diversity, density, and basal area of the SRDS

Sl. no.	Tree species	Family	D	BA	IVI
1	*Bombax ceiba* L.	Malvaceae	1.3	0.16	12.2
2	*Duabanga grandiflora* (Roxb. ex DC.) Walpers	Lythraceae	1.3	0.11	12.2
3	*Lagerstroemia parviflora* Roxb.	Lythraceae	2.5	0.03	18.0
4	*Lagerstroemia speciosa* (L.) Pers.	Lythraceae	2.5	0.23	20.9
5	*Michelia champaca* L.	Magnoliaceae	6.3	1.25	33.3
6	*Neolamarckia cadamba* (Roxb.) Bosser	Rubiaceae	1.3	0.14	12.2
7	*Schima wallichii* (DC.) Korth.	Theaceae	15.0	1.35	59.5
8	*Shorea robusta* Roth.	Dipterocarpaceae	161.3	22.6	465.3
9	*Syzygium cumini* (L) Skeels	Myrtaceae	1.3	0.14	12.3
10	*Tectona grandis* L.f.	Verbenaceae	10.0	2.00	45.6
11	*Terminalia crenulata* (Heyne) Roth	Combretaceae	13.8	1.10	56.0
12	*Toona ciliata* M. Roem.	Meliaceae	2.5	0.03	18.0

SRDS: *Shorea robusta* dominated stand, D: density (individual ha^{-1}), BA: basal area (m^2 ha^{-1}), IVI: important value index

Table 10.4 Tree diversity, density, and basal area of the TGDS

Sl. no.	Tree species	Family	D	BA	IVI
1	*Amoora wallichii* King	Meliaceae	2.5	0.15	11.1
2	*Bombax ceiba* L.	Malvaceae	2.5	0.33	9.8
3	*Dillenia indica* L.	Dilleniaceae	20.0	2.20	36.1
4	*Lagerstroemia parviflora* Roxb.	Lythraceae	3.8	0.34	12.8
5	*Lagerstroemia speciosa* (L.) Pers.	Lythraceae	2.5	0.20	9.8
6	*Michelia champaca* L.	Magnoliaceae	2.5	0.30	11.1
7	*Schima wallichii* (DC.) Korth.	Theaceae	3.8	0.26	12.9
8	*Shorea robusta* Roth.	Dipterocarpaceae	3.8	0.38	12.9
9	*Syzygium cumini* (L) Skeels	Myrtaceae	8.8	1.84	21.1
10	*Tectona grandis* L.f.	Verbenaceae	148.8	14.88	149.6
11	*Terminalia crenulata* (Heyne) Roth	Combretaceae	3.8	0.30	12.9

TGDS: *Tectona grandis* dominated stand, D: density (individual ha^{-1}), BA: basal area (m^2 ha^{-1}), IVI: important value index

crenulata, *Tectona grandis*, and *Michelia champaca*. The tree species richness of *Tectona grandis* dominated stand (TGDS) was 11 which were represented by 10 families and 10 genera (Table 10.4). The IVI, density, and basal area of the dominant *Tectona grandis* were 149.6, 148.8 trees ha^{-1}, and 14.88 m^2 ha^{-1}, respectively. The important dominated tree species associated with *Tectona grandis* in the stand were *Dillenia indica* and *Syzygium cumini*.

The tree species richness of miscellaneous stand (MS) was 45 which were represented by 23 families and 40 genera (Table 10.5), which is about 4 times higher than the species dominated stands. The miscellaneous stands were reported with higher species richness than the species dominated stands (Shukla 2010; Shukla

Table 10.5 Tree diversity, density, and basal area of the MS

Sl. no.	Scientific name	Family	D	BA	IVI
1	*Actinodaphne obovata* (Ness) Blume	Lauraceae	22.5	15.55	6.6
2	*Albizia lucidor* (Roxb.) Benth	Fabaceae	2.5	3.06	2.2
3	*Alstonia scholaris* (L.) R.Br.	Apocynaceae	17.5	9.90	5.6
4	*Amoora wallichii* King	Meliaceae	17.5	19.24	5.6
5	*Ardisia solanacea* Roxb.	Primulaceae	3.8	2.59	2.6
6	*Artocarpus chaplasha* Roxb.	Moraceae	15.0	20.27	5.2
7	*Bauhinia variegata* L.	Fabaceae	5.0	3.30	3.0
8	*Bombax ceiba* L.	Malvaceae	3.8	5.30	2.6
9	*Capparis sikkimensis* Kurz.	Capparaceae	3.8	2.71	3.0
10	*Castanea indica* Roxb.	Fagaceae	2.5	1.34	2.2
11	*Castanopsis indica* (Roxb.) A. Dc.	Fabaceae	8.8	6.05	4.0
12	*Dalbergia stipulacea* Roxb.	Fabaceae	10.0	5.97	4.2
13	*Dillenia indica* L.	Dilleniaceae	17.5	17.05	5.6
14	*Dillenia pentagyna* Roxb.	Dilleniaceae	18.8	8.25	5.7
15	*Drimycarpus racemosus* (Roxb.) Hk. F.	Anacardiaceae	1.3	0.55	1.5
16	*Ficus neriifolia* Smith	Moraceae	2.5	2.51	2.2
17	*Ficus religiosa* L.	Moraceae	2.5	4.24	2.2
18	*Gmelina arborea* Roxb.	Verbenaceae	21.3	18.69	6.1
19	*Lagerstroemia parviflora* Roxb.	Lythraceae	2.5	3.06	2.2
20	*Lagerstroemia speciosa* L.	Lythraceae	35.0	31.89	8.1
21	*Lannea coromandelica* (Houtt.) Merr.	Anacardiaceae	7.5	7.54	3.7
22	*Litsea salicifolia* (Ness) Hook. f.	Lauraceae	28.8	26.20	7.2
23	*Macaranga denticulata* (Blume) Mueller	Euphorbiaceae	3.8	2.12	2.6
24	*Mallotus philippinensis* (Lam) Mueller	Euphorbiaceae	18.8	14.73	5.7
25	*Meliosma pinnata* (Roxb.) Maximowicz	Sabiaceae	10.0	8.80	4.5
26	*Michelia champaca* L.	Magnoliaceae	22.5	31.11	6.6
27	*Myristica longifolia* Wall.	Myrtaceae	15.0	7.07	5.2
28	*Neolamarckia cadamba* (Roxb) Bosser	Rubiaceae	16.3	24.00	5.4
29	*Oroxylum indicum* (L.) Vent.	Bignoniaceae	22.5	23.33	6.6
30	*Phoebe lanceolata* Nees	Lauraceae	5.0	3.61	3.0
31	*Psychotria calocarpa* Kurz.	Rubiaceae	8.75	10.17	4.0
32	*Pterygota alata* (Roxb.) R. Brown	Sterculiaceae	8.8	9.90	4.0
33	*Castnopsis neocavaleriei* A. Camus	Fagaceae	10.0	11.63	4.2
34	*Sapium baccatum* Roxb.	Euphorbiaceae	2.5	2.28	2.2
35	*Schima wallichii* (DC.) Korth.	Theaceae	20.0	16.97	5.9
36	*Shorea robusta* Gaertn. f.	Dipterocarpaceae	26.3	33.82	6.8
37	*Swietenia mahagoni* (L.) Jacq.	Meliaceae	10.0	11.31	4.4
38	*Syzygium balsamum* R. Br. ex Gaertn.	Myrtaceae	13.8	17.28	5.0
39	*Syzygium cumini* (L) Skeels	Myrtaceae	10.0	8.80	4.2
40	*Tectona grandis* L.f.	Verbenaceae	33.8	37.11	7.9
41	*Terminalia bellirica* (Gaertn.) Roxb.	Combretaceae	8.8	10.45	4.0
42	*Terminalia crenulata* (Heyne) Roth	Combretaceae	10.0	10.37	4.2

(continued)

Table 10.5 (continued)

Sl. no.	Scientific name	Family	D	BA	IVI
43	*Tetracera sarmentosa* (L.) Vahl	Dilleniaceae	8.8	7.70	4.0
44	*Toona ciliate* M. Roem.	Meliaceae	18.8	12.96	5.9
45	*Uvaria hamiltonii* Hook. f. & Thomson	Annonaceae	6.3	4.52	3.3

MS: Miscellaneous stand, D: density (individual ha^{-1}), BA: basal area (m^2 ha^{-1}), IVI: important value index

Table 10.6 Tree species richness, biomass, density, and basal area of different forest stands

Stand	TSR	TB	SB	HB	LB	TSB	D	BA
LSDS	15	126.2	10.8	2.3	13.2	152.5	186.3	31.64
TGDS	13	137.7	9.3	3.5	8.9	159.4	163.8	26.83
MCDS	15	142.2	12.0	3.9	13.9	172.0	218.8	29.11
SRDS	14	156.3	8.8	1.4	10.6	177.1	202.5	21.16
MS	56	728.7	16.1	5.4	13.4	763.6	560.0	535.2
SE_m	1.36	1.48	0.59	0.13	0.20	1.81	1.34	1.63
SE_d	1.92	2.09	0.84	0.19	0.29	2.57	1.90	2.30
$P_{0.05}$	**4.19**	**4.55**	**1.82**	**0.42**	**0.62**	**5.59**	**4.13**	**5.01**

LSDS: *Lagerstroemia speciosa* dominated stand, MCDS: *Michelia champaca* dominated stand, SRDS: *Shorea robusta* dominated stand, TGDS: *Tectona grandis* dominated stand, MS: Miscellaneous stand, TSRD: tree species richness (species ha^{-1}), TB: tree biomass (Mg ha^{-1}), SB: shrub biomass (Mg ha^{-1}), HB: herb biomass (Mg ha^{-1}), LB: litter biomass (Mg ha^{-1}), TSB: total stand biomass (Mg ha^{-1}), D: density (trees ha^{-1}), BA: basal area (m^2 ha^{-1})

et al. 2013, 2014, 2017; Rai et al. 2021). In this stand there was no clear-cut dominance of one or two species over the other or they were more or less equally distributed, indicating their miscellaneous nature.

The IVI, density, and basal area of the trees in the stand ranged from 3.9 to 9.4, 1.3 to 10.0 trees ha^{-1}, and 0.05 to 0.88 m^2 ha^{-1}, respectively. This is a clear-cut of this stand. However, the most important species in this stand based on these parameters are *Dillenia indica*, *Lagerstroemia speciosa*, *Quercus castanopsis*, *Syzygium cumini*, *Terminalia crenulata*, *Terminalia bellirica*, *Tetracera sarmentosa*, *Psychotria calocarpa*, *Meliosma pinnata*, *Litsea salicifolia*, *Lannea coromandelica*, *Gmelina arborea*, *Castanopsis indica*, and *Dalbergia stipulacea*. The tree species diversity, density, and basal area in the stands varied significantly among the forest stands (Table 10.6).

The associated tree species richness, density, and basal area in the species dominated stands were much lesser than the MS. Many similar studies attributed higher basal area and density of plant assemblages in the MS due to its higher species richness and population than the species dominated stands (Pande 2001; Sapkota et al. 2009; Shukla 2010; Shukla et al. 2013, 2014, 2017; Rai et al. 2021). Understanding the tree quantitative dynamics of forest stands can provide a clear insight of the structural and functional aspects of forest communities (Pragasan and Parthasarathy 2010).

10.3.2 Biomass and Carbon Storage

The estimated live and litter biomass of different stands varied significantly among the stands (Table 10.6). The MS was estimated with the highest total biomass of 747.1 Mg ha^{-1} followed by the SRDS (156.3 Mg ha^{-1}), MCDS (172.0 Mg ha^{-1}), and TGDS (152.5 Mg ha^{-1}) and least in the LSDS with 126.2 Mg ha^{-1}. The MS was quantified with about 4.3–5.0 times higher total biomass than the four species dominated stands. Moreover, the MS has significantly higher tree (728.7 Mg ha^{-1}), shrub (16.1 Mg ha^{-1}), and herb (5.4 Mg ha^{-1}) biomass than the four species dominated stands also. This is because of significantly higher tree species diversity of the MS (56 tree species ha^{-1}) with significantly higher tree density (560 trees ha^{-1}) and significantly higher basal area (535.2 m^2 ha^{-1}) than the four species dominant stands (Table 10.6). This was further indicated from positive correlation between basal area (R^2 = 0.98) and biomass (R^2 = 0.97) with tree density (Fig. 10.2). Among the species dominated stands, the SRDS was estimated with the highest tree biomass of 156.3 Mg ha^{-1} followed by the MCDS (142.2 Mg ha^{-1}) and TGDS (137.7 Mg ha^{-1}) and least tree biomass of 126.2 Mg ha^{-1} in the LSDS. Mixed species stands that outmatched other stands in total biomass were also reported in earlier studies (da Gama-Rodrigues et al. 2007). In all the stands, the major contribution in the total biomass was by the trees (87.3–96.5%) and the rest by shrubs, herbs, and litters together (3.5–12.7%). The herbs contributed the least to total biomass of the stands (0.7–2.4%). Similar negligible contribution of understory vegetation to the total biomass of the stands was also reported by earlier workers (Shukla 2010; Giri and Rawat 2013; Shukla et al. 2018; Tamang et al. 2021a, b).

The standing biomass of individual species including growing stock volume density (GSVD), above-ground biomass density (AGBD), and below-ground

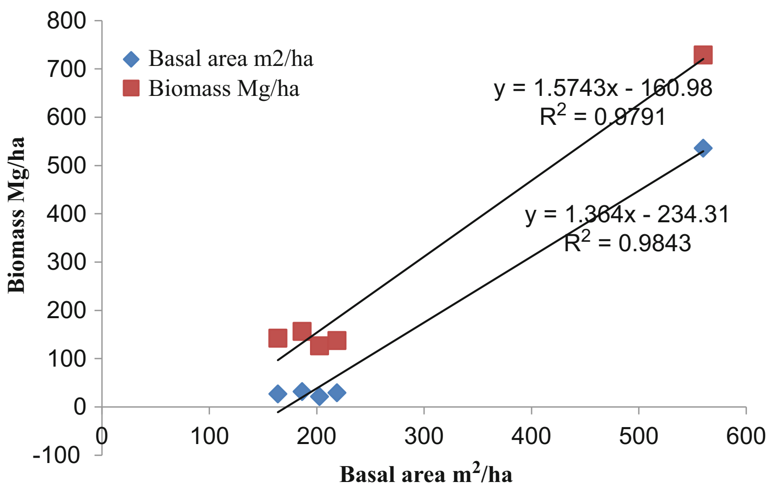

Fig. 10.2 Relationship between tree basal area and biomass with tree density

Table 10.7 Tree biomass and carbon stock density of the LSDS

Tree species	GSVD	AGBD	BGBD	TBD	TCD
Duabanga grandiflora	2.2 ± 0.1	4.3 ± 1.6	1.8 ± 0.1	6.1 ± 0.1	3.1 ± 0.9
Dillenia indica	5.1 ± 1.2	8.1 ± 2.6	1.6 ± 0.1	9.7 ± 0.1	4.9 ± 1.4
Lagerstroemia parviflora	2.1 ± 1.5	8.2 ± 3.2	3.1 ± 0.1	11.3 ± 0.1	5.7 ± 1.6
Lagerstroemia speciosa	5.5 ± 4.7	12.3 ± 0.1	4.1 ± 0.3	16.4 ± 0.3	8.2 ± 0.2
Michelia champaca	5.0 ± 0.7	6.1 ± 0.1	1.1 ± 0.1	7.2 ± 0.2	3.6 ± 0.1
Phoebe lanceolata	1.6 ± 0.1	8.3 ± 0.1	1.8 ± 0.1	10.1 ± 0.1	5.1 ± 0.1
Syzygium cumini	7.9 ± 3.0	9.3 ± 3.0	3.0 ± 0.1	12.3 ± 0.1	6.1 ± 1.5
Shorea robusta	2.8 ± 0.1	4.3 ± 1.2	1.8 ± 0.3	6.1 ± 0.3	3.1 ± 0.8
Schima wallichii	9.7 ± 0.3	6.0 ± 4.1	1.6 ± 2.0	7.6 ± 6.1	3.8 ± 3.0
Tectona grandis	1.3 ± 0.1	9.4 ± 2.1	3.0 ± 0.3	12.4 ± 2.4	6.2 ± 1.2
Toona ciliata	5.0 ± 0.03	11.3 ± 1.1	3.8 ± 0.1	15.1 ± 0.1	7.6 ± 0.6
Terminalia crenulata	1.9 ± 0.2	9.0 ± 2.2	2.8 ± 0.2	11.8 ± 2.8	5.9 ± 1.2
Total	**49.8 ± 11.9**	**96.7 ± 28.2**	**29.5 ± 6.2**	**126.2 ± 34.4**	**63.1 ± 17.2**

LSDS: *Lagerstroemia speciosa* dominated stand, GSVD: growing stock volume density, AGBD: above-ground biomass density, BGBD: below-ground biomass density, TBD: total biomass density, TCD: tree carbon density

biomass density (BGBD) and total biomass density (TBD) of the different species dominated and miscellaneous stands are given in Tables 10.7–10.11. The above-ground, below-ground, and total standing biomass densities of individual tree species of the LSDS are given in Table 10.7. *Lagerstroemia speciosa* was estimated with the highest AGBD (12.3 ± 0.1 Mg ha^{-1}) and BGBD (4.1 ± 0.3 Mg ha^{-1}) and so was the total biomass (16.4 ± 0.3 Mg ha^{-1}). The minimum AGBD, BGBD, and TBD were estimated for *Duabanga grandiflora* and *Shorea robusta*, each with corresponding values of 4.3, 1.8, and 6.1 Mg ha^{-1}, respectively. The contribution of AGB to the total biomass of the species in this stand was in the range of 70.5–84.7%, while the rest (15.3–29.5%) was contributed by the BGB. On an average, the contribution of AGB in TB of the stand was 76.6%. The biomass of important associated species like *Toona ciliata*, *Tectona grandis*, *Syzygium cumini*, *Terminalia crenulata*, and *Lagerstroemia parviflora* in chronological order is 15.1, 12.4, 12.3, 11.8, and 11.3 Mg ha^{-1}, respectively.

Michelia champaca was estimated with the highest AGBD (21.4 ± 6.1 Mg ha^{-1}), BGBD (4.2 ± 3.1 Mg ha^{-1}), and TBD (25.6 ± 9.1 Mg ha^{-1}) in the MCDS (Table 10.8).

This is about 4.6 times more than the species with the lowest AGBD (*Alstonia scholaris*), 4.7 times more than the species with the lowest BGBD (*Bombax ceiba*), and 4.5 times more than the species with the lowest TBD (*Bombax ceiba*). The contribution of the AGBD to the TBD of the tree species in this stand was in the range of 70.1–92.5%, while the rest 7.5–29.9% was contributed by the BGBD. On an average, the contribution of the AGBD to the TBD of the stand was 82.1%. The

Table 10.8 Tree biomass and carbon stock density of the MCDS

Tree species	GSVD	AGBD	BGBD	TBD	TCD
Alstonia scholaris	1.5 ± 0.1	4.7 ± 1.8	2.0 ± 0.1	6.7 ± 3.8	2.4 ± 1.9
Bombax ceiba	1.1 ± 0.9	4.8 ± 1.3	0.9 ± 0.5	5.7 ± 2.2	2.6 ± 1.1
Duabanga grandiflora	4.8 ± 3.0	11.3 ± 0.1	3.6 ± 2.4	14.8 ± 2.4	7.4 ± 1.2
Ficus neriifolia	2.0 ± 0.1	13.3 ± 0.9	1.8 ± 0.1	15.1 ± 0.9	7.6 ± 1.9
Lagerstroemia parviflora	0.9 ± 0.1	6.3 ± 1.1	1.8 ± 0.7	8.1 ± 1.8	4.1 ± 0.9
Lagerstroemia speciosa	3.3 ± 1.9	15.4 ± 2.1	2.0 ± 0.1	17.4 ± 2.2	8.7 ± 2.1
Michelia champaca	10.1 ± 4.8	21.4 ± 6.1	4.2 ± 3.1	25.6 ± 9.1	12.8 ± 4.6
Schima wallichii	36.1 ± 6.8	12.5 ± 1.1	4.0 ± 0.1	16.5 ± 1.1	8.2 ± 2.3
Toona ciliata	1.5 ± 0.1	14.7 ± 0.1	1.1 ± 0.6	15.9 ± 0.8	7.9 ± 1.2
Tectona grandis	3.2 ± 0.1	12.4 ± 3.1	4.0 ± 0.5	16.4 ± 3.6	8.2 ± 7.8
Total	**64.6 ± 15.2**	**116.8 ± 22.4**	**25.4 ± 8.1**	**142.2 ± 30.5**	**71.1 ± 22.2**

MCDS: *Michelia champaca* dominated stand, GSVD: growing stock volume density, AGBD: above-ground biomass density, BGBD: below-ground biomass density, TBD: tree biomass density, TCD: tree carbon density

Table 10.9 Tree biomass and carbon stock density of the SRDS

Tree species	GSVD	AGBD	BGBD	TBD	TCD
Bombax ceiba	1.5 ± 0.1	7.7 ± 0.1	2.0 ± 0.1	9.7 ± 0.1	4.9 ± 0.1
Duabanga grandiflora	5.1 ± 1.2	12.3 ± 4.0	3.6 ± 0.1	15.9 ± 4.1	7.7 ± 2.1
Lagerstroemia parviflora	5.2 ± 2.1	10.3 ± 2.0	3.1 ± 0.1	13.4 ± 2.1	6.7 ± 1.1
Lagerstroemia speciosa	3.0 ± 0.1	4.9 ± 0.7	1.8 ± 0.3	6.7 ± 1.1	3.4 ± 0.5
Michelia champaca	6.2 ± 1.2	8.3 ± 0.1	1.0 ± 0.1	9.3 ± 0.2	4.7 ± 0.
Neolamarckia cadamba	9.2 ± 3.1	11.6 ± 2.0	4.9 ± 0.1	16.5 ± 2.1	8.3 ± 11.1
Syzygium cumini	7.8 ± 3.0	11.2 ± 3.1	3.0 ± 0.1	14.3 ± 3.1	7.1 ± 1.5
Shorea robusta	12.7 ± 2.3	19.1 ± 5.4	6.1 ± 4.5	25.2 ± 11.4	11.8 ± 5.7
Schima wallichii	8.1 ± 0.4	9.1 ± 1.5	2.3 ± 0.2	11.4 ± 1.7	5.7 ± 0.8
Toona ciliata	3.0 ± 0.7	6.3 ± 0.1	1.8 ± 0.1	8.1 ± 0.2	4.1 ± 0.1
Terminalia crenulata	5.0 ± 0.1	7.3 ± 1.1	3.8 ± 0.1	11.1 ± 1.2	5.6 ± 0.6
Tectona grandis	2.2 ± 0.7	9.9 ± 0.4	4.7 ± 0.8	14.6 ± 1.2	9.3 ± 0.6
Total	**68.9 ± 15.0**	**118.1 ± 22.7**	**38.2 ± 7.9**	**156.3 ± 30.6**	**82.7 ± 15.3**

SRDS: *Shorea robusta* dominated stand, GSVD: growing stock volume density, AGBD: above-ground biomass density, BGBD: below-ground biomass density, TBD: total biomass density, TCD: tree carbon density

Table 10.10 Tree biomass and carbon stock density of the TGDS

Tree species	GSVD	AGBD	BGBD	TBD	TCD
Amoora wallichii	2.4 ± 0.4	9.3 ± 0.3	2.6 ± 0.2	11.9 ± 0.4	6.0 ± 0.2
Bombax ceiba	2.1 ± 0.1	5.0 ± 0.6	1.2 ± 0.9	6.2 ± 1.6	3.1 ± 0.8
Dillenia indica	2.1 ± 0.1	4.4 ± 0.7	1.0 ± 0.8	5.4 ± 1.5	2.7 ± 0.8
Lagerstroemia parviflora	2.7 ± 0.2	9.8 ± 4.0	2.6 ± 1.1	12.4 ± 5.1	6.2 ± 2.6
Lagerstroemia speciosa	5.0 ± 0.1	8.0 ± 2.0	3.3 ± 0.1	11.3 ± 2.1	5.7 ± 1.1
Michelia champaca	4.0 ± 0.1	16.3 ± 0.4	6.6 ± 0.2	23.0 ± 0.6	11.5 ± 0.3
Schima wallichii	5.0 ± 0.1	9.0 ± 1.0	2.6 ± 0.5	11.6 ± 1.5	5.8 ± 0.8
Shorea robusta	1.4 ± 0.2	10.5 ± 0.3	1.6 ± 0.5	12.1 ± 0.8	6.1 ± 0.4
Syzygium cumini	4.9 ± 0.1	6.6 ± 1.1	2.5 ± 0.3	9.1 ± 1.5	4.6 ± 0.7
Tectona grandis	12.6 ± 5.4	19.0 ± 1.1	6.8 ± 0.1	25.8 ± 1.3	12.9 ± 0.6
Terminalia crenulata	6.0 ± 0.1	6.1 ± 0.1	2.7 ± 0.1	8.8 ± 0.2	4.4 ± 0.1
Total	**48.6 ± 11.3**	**104.1 ± 21.9**	**33.6 ± 10.0**	**137.7 ± 31.9**	**68.8 ± 15.9**

TGDS: *Tectona grandis* dominated stand, GSVD: growing stock volume density, AGBD: above-ground biomass density, BGBD: below-ground biomass density, TBD: total biomass density, TCD: tree carbon density

other important species in the stand with higher biomass are *Lagerstroemia speciosa* (17.4 ± 2.2 Mg ha^{-1}), *Schima wallichii* (16.5 ± 1.1 Mg ha^{-1}), *Tectona grandis* (16.4 ± 3.6 Mg ha^{-1}), *Toona ciliata* (15.9 ± 0.8 Mg ha^{-1}), *Ficus neriifolia* (15.1 ± 0.9 Mg ha^{-1}), and *Duabanga grandiflora* (14.8 ± 2.4 Mg ha^{-1}).

In the SRDS, the AGBD, BGBD, and TBD of the tree species were estimated in the range of 4.9 ± 0.7–19.1 ± 5.4, 1.0 ± 0.1–6.1 ± 4.5, and 6.7 ± 1.1–-25.2 ± 11.4 Mg ha^{-1}, respectively (Table 10.9).

The maximum standing tree biomass was estimated for *Shorea robusta*, while the least was estimated for *Lagerstroemia speciosa*. The contribution of the AGBD of the species in the stand to the total biomass was in the range of 65.8–89.2% and the rest was contributed by the BGBD (10.8–34.2%). On an average, the contribution of the AGBD to the TBD of the stand was 75.6%. *Neolamarckia cadamba* (16.5 ± 2.1 Mg ha^{-1}), *Duabanga grandiflora* (15.9 ± 4.1 Mg ha^{-1}), *Tectona grandis* (14.6 ± 1.2 Mg ha^{-1}), *Syzygium cumini* (14.3 ± 3.1 Mg ha^{-1}), and *Lagerstroemia parviflora* (13.4 ± 2.1 Mg ha^{-1}) are other species with comparatively higher standing biomass density.

In the TGDS, *Tectona grandis* was quantified with the highest density and basal area, and the species obviously was estimated with the highest AGBD (19.0 ± 1.1 Mg ha^{-1}), BGBD (6.8 ± 0.1 Mg ha^{-1}), and TBD (25.8 ± 1.3 Mg ha^{-1}; Table 10.10). The lowest AGBD (4.4 ± 0.7 Mg ha^{-1}), BGBD (1.0 ± 0.8 Mg ha^{-1}), and TBD (5.4 ± 1.5 Mg ha^{-1}) of the same stand were estimated for *Dillenia indica*. The contribution of the AGBD to the TBD of the species in the stand was 69.3–86.8% and the rest 13.2–30.7% was contributed by the BGBD. On an average, the contribution of the AGBD to the TBD of the stand was 75.6%. Other important

Table 10.11 Tree biomass and carbon stock density of the MS

Scientific name	GSVD	AGBD	BGBD	TBD	TCD
Actinodaphne obovata	4.1 ± 0.7	14.8 ± 0.1	4.2 ± 0.9	19.91 ± 0.9	9.5 ± 0.4
Albizia lucidor	3.1 ± 0.1	6.3 ± 0.7	1.8 ± 0.1	8.1 ± 0.7	4.0 ± 0.3
Alstonia scholaris	0.9 ± 0.1	5.3 ± 0.3	1.8 ± 0.7	7.1 ± 1.0	3.5 ± 0.4
Amoora wallichii	11.0 ± 0.1	17.1 ± 0.1	10.7 ± 0.1	27.8 ± 0.2	13.9 ± 0.1
Ardisia solanacea	7.1 ± 0.1	10.3 ± 2.0	4.8 ± 0.41	15.1 ± 2.4	7.5 ± 1.2
Artocarpus chaplasha	0.9 ± 0.4	6.3 ± 0.5	1.8 ± 0.7	8.1 ± 1.2	4.1 ± 0.6
Bauhinia variegata	3.2 ± 0.1	13.3 ± 0.1	6.6 ± 1.2	19.9 ± 1.3	9.9 ± 0.6
Bombax ceiba	5.5 ± 0.1	10.7 ± 1.2	4.0 ± 0.1	14.8 ± 1.2	7.3 ± 0.6
Capparis sikkimensis	5.9 ± 1.3	6.3 ± 0.8	2.8 ± 0.6	9.1 ± 1.5	4.5 ± 0.7
Castanea indica	0.4 ± 0.2	5.3 ± 0.1	2.8 ± 0.1	8.1 ± 0.1	4.1 ± 0.1
Castanopsis indica	5.1 ± 0.1	15.3 ± 3.0	5.8 ± 0.3	21.1 ± 3.3	10.5 ± 1.1
Dalbergia stipulacea	6.0 ± 0.1	13.3 ± 1.0	4.8 ± 0.6	18.1 ± 1.6	9.1 ± 0.8
Dillenia indica	3.0 ± 0.1	4.3 ± 0.6	1.8 ± 0.1	6.1 ± 0.8	3. ± 10.4
Dillenia pentagyna	2.5 ± 0.9	11.5 ± 2.0	3.42 ± 0.1	14.9 ± 2.1	7.5 ± 1.0
Drimycarpus racemosus	3.0 ± 1.0	3.3 ± 0.5	1.8 ± 0.1	5.1 ± 0.6	2.6 ± 0.3
Ficus neriifolia	9.1 ± 0.1	23.3 ± 6.1	10.8 ± 0.1	34.1 ± 6.1	17.1 ± 3.0
Ficus religiosa	8.5 ± 0.8	19.2 ± 3.1	8.1 ± 1.0	27.3 ± 4.1	13.7 ± 2.1
Gmelina arborea	31.8 ± 0.6	11.1 ± 0.1	6.7 ± 0.1	17.8 ± 0.1	8.9 ± 0.1
Lagerstroemia parviflora	5.1 ± 1.2	12.3 ± 4.0	3.6 ± 0.1	15.9 ± 4.1	7.9 ± 2.0
Lagerstroemia speciosa	9.2 ± 3.1	21.6 ± 2.0	9.1 ± 0.1	30.7 ± 2.1	15.3 ± 1.0
Lannea coromandelica	2.7 ± 0.2	11.8 ± 2.2	3.4 ± 0.6	15.2 ± 2.9	7.6 ± 1.4
Litsea salicifolia	2.7 ± 0.1	9.0 ± 0.3	4.0 ± 0.2	13.0 ± 0.5	6.5 ± 0.2
Macaranga denticulata	2.1 ± 0.1	9.3 ± 0.1	3.8 ± 0.1	13.1 ± 0.1	6.6 ± 0.1
Mallotus philippinensis	6.9 ± 0.1	16.3 ± 2.3	6.8 ± 0.5	23.1 ± 2.8	11.6 ± 1.4
Meliosma pinnata	5.0 ± 0.1	7.3 ± 0.9	2.8 ± 0.1	10.1 ± 1.0	5.1 ± 0.5
Michelia champaca	4.6 ± 1.9	16.2 ± 2.2	6.1 ± 0.1	22.4 ± 2.3	11.2 ± 1.2
Myristica longifolia	4.9 ± 0.1	12.3 ± 3.0	4.8 ± 0.9	17.1 ± 3.9	8.6 ± 1.9
Neolamarckia cadamba	3.0 ± 0.7	8.3 ± 0.1	1.8 ± 0.1	10.1 ± 0.1	5.1 ± 0.1
Oroxylum indicum	3.1 ± 0.1	8.3 ± 0.3	1.8 ± 0.1	10.1 ± 0.4	5.1 ± 0.2
Phoebe lanceolata	6.1 ± 0.1	7.3 ± 1.0	3.8 ± 0.2	11.1 ± 1.2	5.6 ± 0.6
Psychotria calocarpa	3.0 ± 1.0	6.3 ± 0.1	1.8 ± 0.5	8.1 ± 0.6	4.1 ± 0.3
Pterygota alata	13.0 ± 0.1	9.3 ± 0.7	3.8 ± 0.4	13.1 ± 1.1	6.6 ± 0.6
Quercus castanopsis	12.6 ± 1.8	31.0 ± 0.1	11.4 ± 0.1	42.4 ± 0.1	21.2 ± 0.1
Sapium baccatum	33.1 ± 0.1	20.3 ± 5.0	11.8 ± 4.2	32.1 ± 9.2	16.1 ± 4.6
Schima wallichii	7.8 ± 3.0	16.3 ± 3.0	7.1 ± 0.1	23.3 ± 3.1	11.7 ± 1.0
Shorea robusta	8.1 ± 1.5	19.3 ± 4.2	10.1 ± 0.1	29.3 ± 4.9	14.6 ± 2.1
Syzygium balsamum	5.0 ± 0.1	11.3 ± 1.1	3.8 ± 0.1	15.1 ± 1.2	7.6 ± 0.6
Syzygium cumini	3.1 ± 0.1	6.3 ± 1.0	2.8 ± 0.1	9.1 ± 1.1	4.6 ± 0.5
Swietenia mahagoni	2.0 ± 0.9	5.8 ± 0.5	1.0 ± 0.4	6.9 ± 0.8	3.4 ± 0.4
Tectona grandis	6.5 ± 1.5	13.0 ± 6.3	5.2 ± 0.1	18.2 ± 6.5	9.1 ± 3.2
Terminalia bellirica	2.0 ± 0.1	9.1 ± 1.0	4.7 ± 0.1	13.8 ± 1.0	6.9 ± 0.5
Terminalia crenulata	3.0 ± 0.1	4.3 ± 0.7	1.8 ± 0.3	6.1 ± 1.1	3.1 ± 0.5

(continued)

Table 10.11 (continued)

Scientific name	GSVD	AGBD	BGBD	TBD	TCD
Tetracera sarmentosa	3.1 ± 1.4	3.3 ± 1.0	1.8 ± 0.6	5.1 ± 1.6	2.6 ± 0.8
Toona ciliata	1.8 ± 0.2	9.0 ± 2.2	2.8 ± 0.2	11.8 ± 2.5	5.9 ± 1.2
Uvaria hamiltonii	4.1 ± 0.1	14.3 ± 3.0	5.8 ± 1.7	20.1 ± 4.8	10.1 ± 2.4
Total	**271.1** ± **29**	**516.3** ± **7**	**212.4** ± **18**	**728.7** ± **89**	**364.4** ± **4.5**

MS: Miscellaneous stand (MS), GSVD: growing stock volume density, AGBD: above-ground biomass density, BGBD: below-ground biomass density, TBD: total biomass density, TCD: tree carbon density

species with higher biomass density of the stand were *Michelia champaca* (23.0 ± 0.6 Mg ha^{-1}), *Lagerstroemia parviflora* (12.4 ± 5.1 Mg ha^{-1}), *Shorea robusta* (12.1 ± 0.8 Mg ha^{-1}), *Amoora wallichii* (11.9 ± 0.4 Mg ha^{-1}), *Schima wallichii* (11.6 ± 1.5 Mg ha^{-1}), and *Lagerstroemia speciosa* (11.3 ± 2.1 Mg ha^{-1}).

The biomass of the species is distributed normally as is expected from a species diverse stands with the range of 5.1 ± 0.6-42.4 ± 0.1 Mg ha^{-1} (Table 10.11). The tree species estimated with the lowest TBD in the MS was *Drimycarpus racemosus* and *Tetracera sarmentosa*, while Quercus *castanopsis* was quantified with the highest TBD. Other tree species estimated with higher standing biomass was *Ficus neriifolia* (34.1 ± 6.1 Mg ha^{-1}), *Sapium baccatum* (32.1 ± 9.2 Mg ha^{-1}), *Lagerstroemia speciosa* (30.7 ± 2.1 Mg ha^{-1}), *Shorea robusta* (29.3 ± 4.9 Mg ha^{-1}), *Amoora wallichii* (27.8 ± 0.2 Mg ha^{-1}), *Ficus religiosa* (27.3 ± 4.1 Mg ha^{-1}), *Mallotus philippinensis* (23.1 ± 2.8 Mg ha^{-1}), *Schima wallichii* (23.3 ± 3.1 Mg ha^{-1}), *Michelia champaca* (22.4 ± 2.3 Mg ha^{-1}), *Castanopsis indica* (21.1 ± 3.3 Mg ha^{-1}), *Uvaria hamiltonii* (20.1 ± 4.8 Mg ha^{-1}), and *Actinodaphne obovata* (19.91 ± 0.9 Mg ha^{-1}). The contribution of the AGBD of the tree species in the MS to the TBD was 61.5–84.1% and the rest 15.9–38.5% was contributed by the BGBD. On an average, the contribution of the AGBDl to the TBD of the stand was 70.9%.

Similar allocation of biomass to the aerial and below-ground parts of the tree was reported from many species dominated stands like *Populus deltoides* (Swamy et al. 2006; Singh and Lodhiyal 2009; Yadava 2010; Rizvi et al. 2011; Arora et al. 2014); *Eucalyptus* hybrid, *Eucalyptus tereticornis*, *Dalbergia sissoo*, and *Pinus roxburghii* (Negi and Sharma 1985; Rana and Singh 1990; Bargali et al. 1992; Lodhiyal and Lodhiyal 2003; Rawat and Negi 2004); *Acacia catechu* and *Shorea robusta* (Sharma et al. 2010); *Acacia tortilis*, *Acacia senegal*, and *Prosopis juliflora* (Singh 2005); *Quercus semecarpifolia* (Subedi 2004); *Pinus tabulaeformis* (Liu and Yu 2009); *Caragana korshinskii* (Zhang et al. 2009); *Schima superba* (Ali et al. 2014); *Shorea robusta* (Shrestha et al. 2000; Koul 2004); *Tectona grandis* (Behera and Mohapatra 2015); *Ailanthus excelsa* (Pande et al. 1988; Giri and Rawat 2013); and *Pinus massoniana* (Justine et al. 2015) and *Calligonum polygonoides* (Singh and Singh 2017). All these studies also reported major proportion of total biomass was contributed by the aerial parts of the tree. The biomass allocation of the tree species varied narrowly among the species but the total biomass of the stands varied widely between the MS and species dominated stands. Biomass carbon is generally estimated as half of the biomass and the factors that influence biomass production also directly influence the carbon stock (IPCC 2000; Shukla et al. 2019; Rai et al. 2021; Tamang et al. 2021a, b). Therefore, the carbon storage of the studied forest stands also exhibited the same trends as biomass. Biomass production and carbon accumulation by the trees vary within the forest stands, forests, and among the regions due to population, genetic, morphological, and environmental variation along with management practices and disturbance (Mohandass et al. 2016).

Quantifying biomass or biomass carbon by the tree species and partitioning to its different organs will aid in developing silvicultural techniques to regulate life history strategies of the trees for improving forest productivity and its sink capacity (Niinemets et al. 2007). Biomass assessment of the trees will be a vital management tool to select the dominant species of different forests to understand various ecological processes of that particular forest ecosystem. This is because dominant tree species of plant assemblages in a forest ecosystem mainly regulate the dynamics of energy through its growth and development processes sustaining the material cycle between biotic and abiotic components of that system (Devi and Yadava 2009). Quantified biomass information of tree species in forests will supplement the regional and global climate change mitigation strategies through regulation of carbon cycling and sequestration processes. Thus, the present quantification of biomass stored by the tree species in different stands of the forest will be helpful to understand the contribution of tree species and forest stands to net regional carbon emission and their potential for viable sink (Chhabra and Dadhwal 2004).

10.3.3 Ecosystem Carbon Stock

The Ecosystem Carbon Stock (ECS) density in different forest stands of JNP is given in Table 10.12. The ecosystem carbon stock density and the component carbon stock density contributing it varied significantly. The ECS of the stands was estimated in the range of 145.8–454.3 Mg C ha^{-1}. The largest sink was the MS followed by the LSDS with carbon stock of 171.9 Mg ha^{-1}, the MCDS with 163.6 Mg C ha^{-1}, and the SRDS with 162.6 Mg C ha^{-1} and the smallest sink was the TGDS. The trees, shrubs, herbs, litter, and soil in the MS also had stocked the highest amount of carbon, while these components in the TGDS stocked the least amount of carbon. This is because the amount of biomass estimated for these two stands was also the highest and lowest, respectively. Similar ecosystem carbon stock of different forest stands was abundantly reported across the globe (Swamy et al. 2003; Pragasan 2014; 2015; Sahu et al. 2016; Yadav et al. 2017).

The MS was quantified with 2.64–3.12 times higher sink capacity stock than the other forest stands analyzed. This indicates the importance of biodiversity richness as the MS was the most diverse stand than the other species dominant stands. Studies had confirmed the functional relationships between plant diversity and carbon storage (Spehn et al. 2005; Erskine et al. 2006; Fornara and Tilman 2008; Ruiz-

Table 10.12 Ecosystem carbon stock in different stands

Stand	Tree	Shrub	Herb	Litter	Soil (0–60 cm)	Total
LSDS	70.3	4.0	1.4	4.8	91.4	**171.9**
MCDS	64.0	5.4	3.9	6.3	84.0	**163.6**
SRDS	62.0	4.2	3.5	4.0	88.9	**162.6**
TGDS	56.8	4.9	2.3	5.9	75.9	**145.8**
MS	327.9	7.3	5.4	6.0	107.7	**454.3**
SE_m	0.11	0.09	0.09	0.10	0.11	0.10
SE_d	0.16	0.12	0.12	0.15	0.16	0.14
p = 0.05	**0.34**	**0.27**	**0.27**	**0.32**	**0.34**	**0.30**

LSDS: *Lagerstroemia speciosa* dominated stand, MCDS: *Michelia champaca* dominated stand, SRDS: *Shorea robusta* dominated stand, TGDS: *Tectona grandis* dominated stand, MS: Miscellaneous stand (MS)

Jaen and Potvin 2010; Zhang et al. 2011), for instance direct relationship between vegetation growth and nutritional status (Attiwill 1979; Evans 1979) and between density of forest stands and nutrient demands (Dicus and Dean 1997).

The cumulative influence of higher diverse tree species of the MS enhanced its partitioning and building up of carbon than the lesser tree diverse species dominant stands (Mulder et al. 2001; Sariyildiz and Anderson 2003; Vesterdal et al. 2008). The growth and development of diverse trees in forests are strongly associated with site quality factors, inter- and intra-specific interactions, disturbances, and silvicultural procedures (Chave et al. 2005; Urquiza-Haas et al. 2007; Do et al. 2010; Con et al. 2013; Karthick and Pragasan 2014). The site quality factors of mix species stand was better than the species dominant stand. Therefore, the growth and development of this stand was better with higher productivity and sink capacity than the species dominated stand. Moreover, higher productivity of the MS also indicates efficient utilization of resources like light, moisture, and nutrients by the diverse species in the stands with overall synergistic inter- and intra-specific interactions among the species supporting their better growth and development. This is because plant assemblages with high species diversity efficiently utilize the available resources with higher net primary production and thus higher carbon sequestration (Catovsky et al. 2002; Kirby and Potvin 2007).

Consequent of the higher diversity in the MS with synergistic interactions among the species and higher productivity, there was higher soil organic matter buildup with higher organic carbon in its soil, further regulating the ecological process and interaction of the MS ecosystem (Hättenschwiler and Gasser 2005; Mitchell et al. 2007; Xiao-wen et al. 2009; Berg et al. 2010; Aponte et al. 2012; FAO 2017). This is because the primary productivity of the stands is mainly influenced by the amount of its litter production regulating the material cycle of the system (Steinke et al. 1993; Lee 1995; Ashton et al. 1999; Hossain and Fazlul-Hoque 2008). This is evidenced from higher litter carbon of the MS (Table 10.12), while in our earlier study we already reported higher litter production of the MS (Sapkota et al. 2009). Studies already proved litter as a vital link between forest ecosystem components and processes regulating its productivity (Purahong et al. 2014; Uriarte et al. 2015).

Forest management can viably and efficiently sequester carbon due to its permanency both in soil and biomass (Whitmore et al. 2015; Lal 2016; Minasny et al. 2017). Therefore, land management with the introduction of trees particularly for rehabilitation of the deforested, waste, and degraded lands will not only offset emission but also improve the sink capacity (Powlson et al. 2011; Badgery et al. 2014; Paustian et al. 2016; Sreenivas et al. 2016). Land management through tree-based options will not only enhance ecosystem carbon buildup but also in true sense will regulate atmospheric carbon dioxide both as avoided emission (Sanderman and Baldock 2010) and net transfer carbon from the atmosphere (Powlson et al. 2011), supporting the ambitious 4 per mille global initiative (Lal 2016; Minasny et al. 2017).

10.4 Conclusion

Mixed species forest stands are better carbon sink with higher ecosystem carbon stock than the species dominant stands at Terai zone in eastern Himalayas. *Tectona grandis*, *Shorea robusta*, *Michelia champaca*, and *Lagerstroemia speciosa* are the most important commercial timber species of the region. Therefore, it is advocated to conserve forest for climate change mitigation. Unfortunately, forests are now the net source of atmospheric CO_2 which requires to be supplemented with tree-based land uses in non-forested landscapes to offset emission. Therefore, carbon management through forest and other tree-based vegetation is one of the top most viable strategies to mitigate the global climate changes. Developing plantations with high-value timber species like *Tectona grandis*, *Shorea robusta*, *Michelia champaca*, and *Lagerstroemia speciosa* which has better potential to enhance sink capacity as carbon farming initiative in the non-forested landscape of the region is recommended. However, there is more need to identify the location and mechanism for this sink locally and regionally. Initiating plantation programs in the region with supportive policy platforms and action with these high-value timber species in participatory mode will not only supplement the forest to offset emission through avoided deforestation but also will restore or rehabilitate the degraded or deforested lands along with multiple social and ecological benefits. Management strategies should also consider the disturbance factors to encourage region-specific heterogeneous plantations so that semi-natural forest vegetation is developed also on non-forested landscape without compromising the timber demands while accommodating social and ecological benefits. For plantation heterogeneity, it is recommended to let these plantations mature which needs incentives to the growers through pro-people policy decisions. Success of these strategies needs systematic and holistic research to understand these plantations at various successional stages throughout the age classes of natural rotation of species. Regional patterns, magnitude, and driving mechanisms of terrestrial carbon sinks and sources are dynamic and still unclear which need systematic research efforts. Absence of information on land use and land cover change, i.e., LULCC, is the major uncertainty to quantify carbon fluxes in and out of a system. In the present study we also were unable to quantify the carbon fluxes in and out of the studied forest stands for the want of LULCC information databases of the study region. Carbon exchange between these forest stands and the atmosphere would have generated more accurate estimation of carbon budgets of the study region for efficient policy support and management decisions. Therefore, comprehensive research is required to understand and generate information on the dynamics of LULCC. In spite of this limitation, the study could identify the best tree species for the region on which management strategies and policy decisions can be formulated to initiate carbon farming in the region at non-forested landscapes while conserving the remaining natural forests. The study generated baseline information for future research in the region to understand the sink capacity and carbon fluxes of other forested landscapes.

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Chapter 11
A People's Biodiversity Register of Henry's Island, Indian Sundarban

Riya Chakraborty, Nabendu Sekhar Kar, and Raja Ghosh

Abstract People's Biodiversity Register (PBR) is one of the popular methods of registering biodiversity in consultation with the local people of respective areas. PBR portrays the richness and status of biodiversity and traditional knowledge system and effective uses and values ascribed to the floras and faunas. Located at the sea face of Namkhana Block of Indian Sundarban, Henry's Island is famous for its mangroves and associated species, sandy beaches and red crabs, fisheries and tourism. After collecting baseline information from secondary sources and maps and satellite images, a PBR was prepared for Henry's Island by interviewing 50 locals and by focus group discussions during 23–26 February 2015. A total of 40 flora (12 timber plants including 7 mangroves, 1 medicinal plant, 9 grasses and shrubs, 10 crops and vegetables, 8 fruit trees) and 63 fauna (8 wild and 6 domestic mammals, 13 birds, 8 insects and crustaceans, 9 reptiles, 3 snails, 10 brackish water fishes, 6 freshwater fishes) species were registered. Further, as recognised by responders, species distribution patterns were documented by correlating the land use and land cover classes. Anthropogenic interference, in recent years, in forms of expansion of aquaculture, over-tourism, timber cutting and encroachment possesses immense threat to this biodiversity-rich area of Indian Sundarban.

Keywords Biodiversity · People's Biodiversity Register · Environmental degradation · Mangrove fragmentation · Conservation

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11.1 Introduction

Scientific documentation of biodiversity is considered as the first step towards sustainable management, use and conservation of forest resources. Forests, 'more than just trees', comprising plants, animals and microorganism, are a complex mélange of diversities at different levels: ecosystem, landscape, species, population and genetic (CBD 2008). In fact, forests foster most of terrestrial biodiversity: 80% of amphibians, 75% of birds and 68% of mammals (FAO-UNEP 2020). Thus, biodiversity conservation is directly linked with human interaction with forests, forest resource utilisation and conservation of forests. Between 2015 and 2020, the world has lost 10 million ha of forests per year (FAO-UNEP 2020). Although the rate is lower than the last decades, indiscriminate deforestation has resulted in habitat loss, fragmentation and species extinctions (Brooks et al. 2002; Symes et al. 2018). The tropical forests, sheltering two-thirds of the world's biodiversity (Giam 2017), are considered the biodiversity hubs of the world, globally most threatened from deforestation (Hansen et al. 2013). Increasing terrestrial human footprints especially into tropical forests in the form of agriculture and other economic uses are aggravating the present environmental crisis towards a new wave of worldwide extinction (Venter et al. 2016; Barlow et al. 2016; Newbold et al. 2016; Alroy 2017; Symes et al. 2018). Even during last few decades, the frequent outbreaks of pandemics and epidemics like MERS, SARS, 2009 H1N1, HIV, Ebola and COVID-19 are linked with increasing intimate associations of human and wildlife in a rapidly crowding world (Dobson et al. 2020; Bloomfield et al. 2020).

The Sundarban, the largest mangrove forest in the world (~10,000 km^2), shared by Indian state of West Bengal (38%) and Bangladesh (62%) has been subjected to human encroachment since historical times. Although reclamation of the northern margins of the forest started during the thirteenth century (Eaton 1990), institutional clearings for agriculture were started in 1783 based on policy decisions under British colonial rule (Pargiter 1934). In between 1776 and 2014, the Indian part of Sundarban, known as Sundarban Biosphere Reserve (SBR), has lost 72% of its forests and presently consists of both reclaimed inhabited areas and non-reclaimed forests (Ghosh et al. 2015). Although deforestation has been restricted since 1971–1973 by applying several legal instruments, ~6% of forest area loss in the last few decades has been reported primarily due to coastal erosion and associated hazards (Samanta and Hazra 2017; Kundu et al. 2020). In 1987 SBR was recognised as a World Heritage Site with the prime objective of biodiversity conservation (Ghosh et al. 2015). As recorded till date SBR houses 2876 species (40 microbes, 270 algae, 128 phytoplanktons, 167 lichens, 180 mangroves and associated flora, 67 protozoa, 177 mollusca, 57 polychaetes, 2 xiphosurans, 329 crustaceans, 114 spiders, 121 mites, 497 insects, 364 fishes, 11 amphibians, 71 reptiles, 234 aves and 47 mammals) and much of them are irreplaceable and considered India's biodiversity treasures like the Gangetic dolphin or the iconic Royal Bengal Tiger (WWF 2017). The Sundarban provides 'provisioning, regulating, supporting and cultural' ecosystem services that make it valuable, unique, celebrated as well as complex and delicate.

The human population in SBR recorded a boom since independence, from 1.15 million in 1951 to 4.44 million in 2011(Ghosh et al. 2015), and unfortunately about 43.5% of them live below the nationally designated poverty line (DasGupta and Shaw 2014) with an average unemployment rate of 63% (WWF 2011). Traditionally, the Sundarban dwellers are engaged mostly in monocropping and forest-dependent livelihoods like fishing, shrimp fry and crab collection and honey and bee-wax collection. Rapid population increase on one hand and chronic poverty and unemployment on the other have significantly increased the human footprint into the existing forest. The forest margins are under extreme threat of human encroachment and resulting degradation (Das and Datta 2016). Additionally, tourism and saltwater shrimp farming are gaining popularity in recent years (World Bank Report 88,061, 2014). It leads to further degradation of the sensitive tidal-forest environment and is exhibited by several man–animal conflicts (Das 2013; Das and Jana 2018), ill-effects of aquaculture and shrimp-farming (Das and Datta 2016; Basu et al. 2021) and conservation conflicts between locals and forest officials (Ghosh 2015). Historical reclamations in Sundarban resulted in the extinctions of several species like water buffalo, the swamp deer, Javan rhinoceros, the gharial and the *Chitra* turtle. Change in faunal composition is also reported as more and more species are being included in the International Union for Conservation of Nature (IUCN) Red List of threatened species (WWF 2017). At present, the cost of environmental degradation and biodiversity loss is estimated to be INR 6.7 billion (2009 rate; 1 USD = INR 45) (World Bank Report 88,061 2014), making the Indian Sundarban an 'endangered ecosystem' (Begam et al. 2020).

One of the main hindrances to biodiversity conservation strategies is the lack of spatial data on biodiversity (Betts et al. 2017) which is also applicable for SBR (WWF 2017). People's Biodiversity Register (PBR), devised in India in 1995 by adapting the concept of Community Biodiversity Registers (CBRs), is one of the popular methods of registering biodiversity in consultation with the local people of the respective areas (Gadgil et al. 2000). Mandated under National Biological Diversity Act of India (2002), PBR portrays the richness and status of biodiversity and traditional knowledge system and effective uses and values ascribed to the floras and faunas. Though CBRs are performed in different parts of the world (Subedi et al. 2013; Fabricius and Pereira 2015), conceivably the largest drive is recorded in the case of Indian PBRs – documenting 91,200 species of animals and 45,500 species of plants in 10 biogeographic regions of the country (Outlook India 2020).

Although several PBRs have been prepared throughout the country, PBR studies in SBR are rare. An NGO named Lokamata Rani Rashmoni Mission conducted a PBR programme in six villages of Jaynagar II block during 2007–2008 (LRRM 2021). During 2008–2020, the West Bengal Biodiversity Board conducted 24 projects documenting biodiversity of the state, among which 2 reports were directly linked with fish species and migratory birds of the SBR districts (http://wbbb.wb.gov.in/status_project.php). Since colonial times, bio-resource documentation in this part of the world was primarily done by the forest and/or revenue department or by the experts appointed by scientific institutions or societies. While species composition of SBR is well documented in several reports, records of people's perceptions on the available bio-resource, its use and management are infrequent. Studies dealing with the managerial aspects linked with anthropogenic pressure hardly follow a bottom-up approach. In most cases, locals play little role in decision-making and management operations regarding mangrove conservation, man–animal conflicts, etc. (Ghosh and Ghosh 2019). PBRs, in addition to bio-resource documentation, provide an excellent opportunity to interact with locals, which helps in identifying man–environment dynamics. In this study, such an endeavour is attempted for the first time in SBR. Located at the coastal margin of Namkhana Block of SBR, Henry's Island is famous for its mangroves and associated species, sandy beaches and red crabs, fisheries and tourism (Fig. 11.1). This mangrove patch

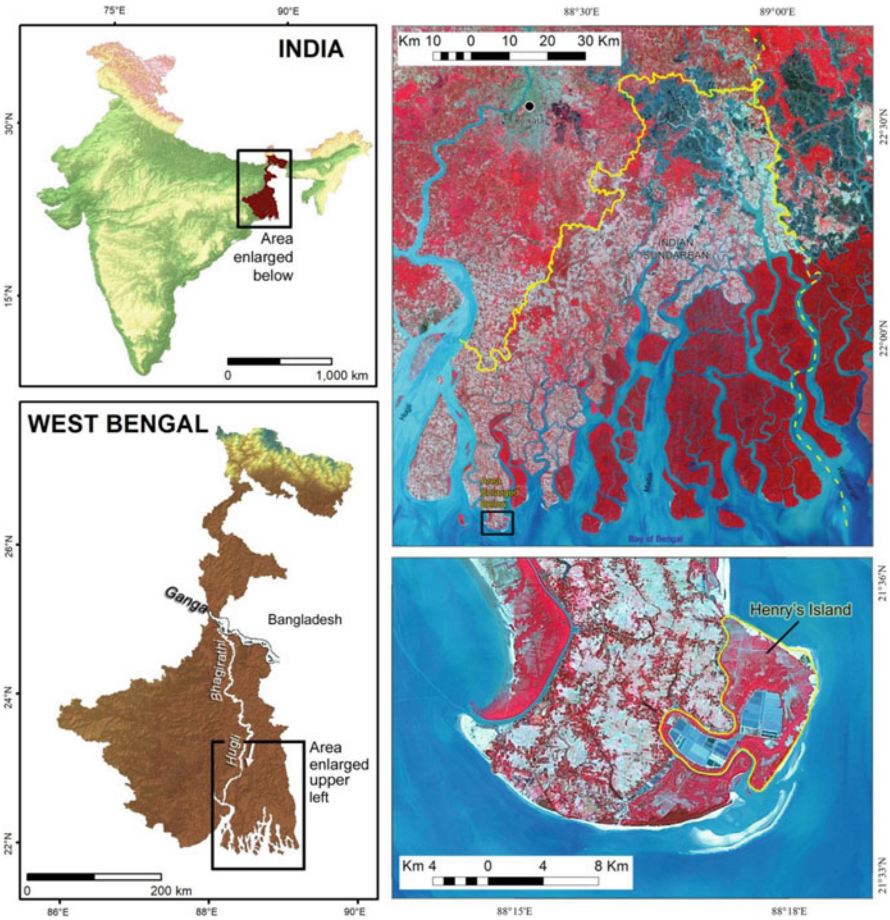

Fig. 11.1 Indian Sundarban or Sundarban Biosphere Reserve (SBR) consists of both reclaimed inhabited areas and non-reclaimed forests (left upper panel) and is delimited by Dampier–Hodges line (shown by yellow line) in the north. Henry's Island, located at the south-eastern sea face of Namkhana Block of SBR (left lower panel), is famous for its mangroves and associated species, sandy beaches and red crabs, fisheries and tourism. For image details see Table 11.2

(470 ha), as a proxy of the SBR, comprising the natural as well as the human elements, is an excellent choice to study its biodiversity and anthropogenic interference. The primary objective of this study is to prepare a PBR by consulting locals living near the forest margin and the second is to identify threats due to an increasing human footprint.

11.1.1 Study Area

Henry's Island (470 ha; 21° 34′ 30" N and 88° 16′ 30″ E) is located at the south-eastern sea face of Namkhana Community Development Block of SBR (Fig. 11.1). It is a famous coastal resort and well-known for its brackish water fisheries farm. The island is separated from Namkhana on its north-west and Fredrick Island on its west by the Bakkhali River. Being a part of the Namkhana Reserve Forest, the island was covered by dense mangroves before 1978 (Fig. 11.2). On 16 February 1970 the West Bengal State Fisheries Department acquired 200 ha land of the island for expansion of aquaculture from the State Forest Department (Chakraborty 2015). The State Fisheries Development Corporation (SFDC), a government enterprise under the West Bengal State Fisheries Department, got permissive possession of the 200 ha land on 27 Jan 1978 for development of a brackish water fish farm with the assistance of scientists of Central Inland Fisheries Research Institute (CIFRI). In between 1978 and 1984, out of 200 ha, 149.3 ha of the mangroves was deforested for setting up the fisheries farm (Planning Commission of India 1981; Chakraborty 2015). Later in 1991, the project area was leased to a private farm named 'Sunderban Aquatic Farms Ltd.'. However, the State Fisheries Department took the land back from the private firm and handed it over again to SFDC in 2000. At present, the fisheries project area is divided into two sectors: Sector A (67 ha) and Sector B (40 ha) with a total of 54 aquaculture ponds and surrounded by an artificial canal named Pukurberia (Chakraborty 2015; Fig. 11.3). Additionally, the north-eastern part of the beach of Henry's Island is used by the local fisherfolks, mainly from nearby Kalistan area (Haripur village), for setting up fish drying camps (Fig. 11.3).

Recently, Henry's Island has experienced a huge growth in tourism, especially during the last two decades (Sahana et al., 2020). It's become an integral part of the Fresurgunj–Bakkhali coastal tourism circuit. Serene beaches with red crabs, dense mangroves and fresh fish directly from the firm are its major attractions. Under an ecotourism project SFDC has built two resorts, a cafeteria, and a watchtower to attract tourists. In winter it records footfall in the thousands, mostly as day travellers from nearby Bakkhali coastal resort (Fig. 11.3). As noticeable from the discussion above, Henry's Island has a very recent history of reclamation and is highly vulnerable from anthropogenic interference (Sahana et al., 2021). Thus, selection of this site to conduct a PBR and to identify the threats of human-led environmental degradation in Indian Sundarban goes in line with the objective of the study.

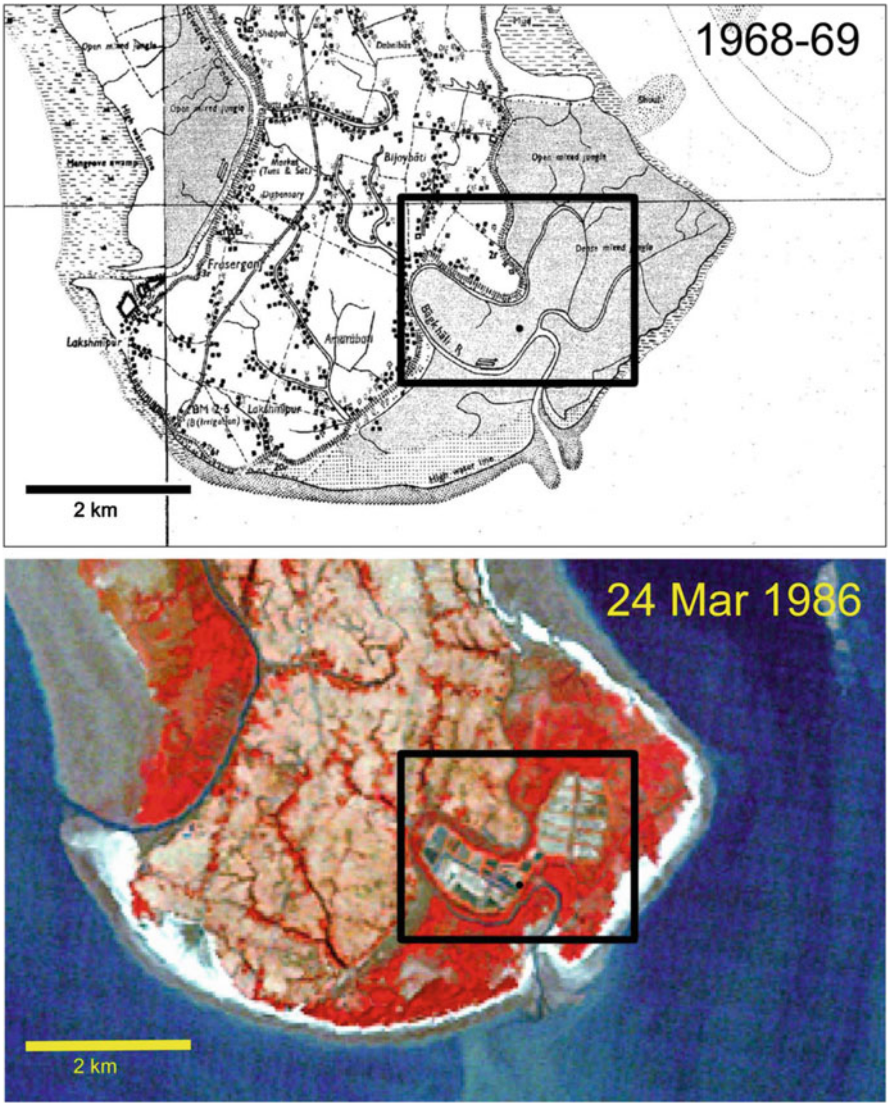

Fig. 11.2 Institutionalised reclamation of a part (149.3 ha) of the Henry's Island (470 ha) occurred in between 1978 and 1984 by the State Fisheries Development Corporation, a government enterprise under the State Fisheries Department with the assistance of scientists of Central Inland Fisheries Research Institute for development of a brackish water fish farm. For map/image details see Table 11.2

Fig. 11.3 The north-eastern part of the beach of Henry's Island is used by local fisherfolks from the nearby Kalistan area for setting up fish drying camps

11.2 Materials and Methods

11.2.1 Peoples Biodiversity Register

After collecting baseline information from secondary sources, maps and satellite images, a PBR is prepared for Henry's Island, mostly following the National Biodiversity Authority (2009) framework. During 23–26 February 2015, PBR field data were collected by interviewing 50 locals from the adjoining villages and through focus group discussions (FGD) – the local fisherfolks, labourers associated with the Henry's Island fisheries farm, field staffs of the forest department and personnel associated with tourism activities. Then the data were collated, analysed and cross-checked with the information provided by the state forest officials of Bakkhali Range and SFDC. As mentioned by the forest officials, according to their internal report, Henry's Island nurtures a total of 108 species of flora and fauna. Officials from the SFDC provided a list of common species found on Henry's Island (including the farm fish) as shown in Table 11.1.

As the locals of the forest margin villages took part in the PBR, they also reported about domestic and agricultural biodiversity, which were also documented. Apart from agriculture, a majority of the villagers are fisherfolks. They informed about fish species collected from sea and estuaries and in freshwater and brackish water aquaculture ponds. The PBR format consisted of three structured questionnaires. The first one was 'landscape and people' through which information on terrain characteristics, land cover and land use, and population characteristics – occupation, income level and everyday use of natural resources, etc. – was noted. The second one was on floral diversity and was divided into two sections: natural vegetation (timber plants, fruit plants, medicinal plants, grass–shrubs and others) and agriculture (crop,

Table 11.1 List of common flora and fauna found in Henry's Island (Source: SFDC office, Henry's Island)

Common plants			
Sl. no.	Common name	Local name	Scientific name
1	Tall-stilt mangrove	Garjan	*Rhizophora apiculata*
2	Blind-your-eye mangrove	Gewan	*Excoecaria agallocha*
3	Api-api/Indian mangrove	Kalo baine	*Avicennia alba*
4	Grey mangrove	Peara baine	*Avicennia marina*
5	Indian mangrove	Karang/Jat baine	*Avicennia officinalis*
6	Burma/oriental mangrove	Kankra	*Bruguiera gymnorrhiza*
7	Lenggadai	Bokul kankra	*Bruguiera parviflora*
8	Cedar mangrove	Passur	*Xylocarpus mekongensis*
9	Tora	Tora	*Aegialitis rotundifolia*
10	Mangrove date palm	Hetal/bagra	*Phoenix paludosa*
11	White-flowered black mangrove	Kripal	*Lumnitzera racemosa*
12	Portia tree	Hubli/parash pipul	*Thespesia populnea*
13	Annual sea-blite	Nona-shak	*Suaeda maritima*
14	Seepweeds	Giria-shak	*Suaeda nudiflora*
15	French tamarisk	Nona-jhau	*Tamarix gallica*
16	Holy mangrove	Hargoja	*Acanthus ilicifolius*
17	Cannonball mangrove	Dhundul	*Xylocarpus granatum*
18	Neem	Neem	*Azadirachta indica*
19	Coconut	Narkel	*Cocos nucifera*
20	Date palm	Khejur	*Phoenix sylvestris*
21	Java apple	Jamrul	*Syzygium samarangense*
22	Indian gooseberry	Amloki	*Phyllanthus emblica*
Common animals[a]			
1	Leopard cat	Baghrol	*Prionailurus bengalensis*
2	Wild boar	Buno suor	*Sus scrofa*
3	Spotted deer	Chital harin	*Axis axis*
4	Red ghost crab	Lal kankra	*Ocypode macrocera*
5	Cobra	Keutia	*Naja naja*
6	Grey heron	Bok	*Ardea cinerea*
7	Little cormorant	Pankouri	*Phalacrocorax niger*
8	Indian python	Ajagar	*Python molurus*
9	Indian cobra	Kharisha	*Naja Kautia*
10	Indian softshell turtle	Ganga kachim	*Trionyx gangeticus*
11	Red-wattled lapwing	Hattiti	*Vanellus indicus*
12	Red jungle fowl	Bon-morog	*Gallus gallus*
13	Black drongo	Finge	*Dicrurus macrocercus*
14	Purple heron	Lalche-bok	*Ardea purpurea*
15	Buff-spotted flameback	Kaththokra	*Chrysocolaptes lucidus*
16	Giant/Goliath heron	Boro bok	*Ardea goliath*
17	Rohu	Rui	*Labeo rohita*
18	Katla	Katla	*Catla catla*

(continued)

Table 11.1 (continued)

Common plants			
Sl. no.	Common name	Local name	Scientific name
19	Mrigal	Mrigal	*Cirrhinus cirrhosus*
20	Prawn	Chingri	*Dendrobranchiata* sp.
21	Mullet	Parshe	*Liza parsia*
22	Bombay duck	Lotte	*Harpadon nehereus*
23	Silver pomfret	Pomfrete/chnada	*Pampus argenteus*
24	Barramundi	Bhetki	*Lates calcarifer*
25	Paradise threadfin	Topshe	*Polynemus paradiseus*
26	Mudskippers	Gule/gulla/menomach	*Boleophthalmus boddarti*
27	Tade mullet	Bhangan	*Liza tade*

[a] Several migratory birds come to Henry's Island in winter

Table 11.2 Details of maps and images used in the study

Data particulars	Imaging date/ year of survey	Scale/ resolution	Tile/scene/ map identity	Source	Reference figure
Landsat-8 OLI	8 Mar 2015	30 m	p138-r045	United States Geological Survey (USGS)	Fig. 11.1
SoI metric topographical map	1968–1969	1:50,000	79 C/06	Survey of India (SoI)	Fig. 11.2
Landsat-5 TM	24 Mar 1986	30 m	p138-r045	USGS	Fig. 11.2
Google Image	2021	1 m	–	CNES/Airbus (Google Maps)	Fig. 11.3
Google Image	2021	1 m	–	CNES/Airbus (Google Earth)	Fig. 11.4

fruit, etc.). The third was on fauna species and consisted of two sections: wild animals (mammals, birds, insects and crustaceans, reptiles, snails and fishes) and domestic animals. Land use and land cover categories of Henry's Island were identified from Google Images followed by ground-truth verification during field inspection. Then the species distribution pattern, as recognised by responders, was documented by correlating the land cover and land use classes (Fig. 11.3).

11.2.2 Identifying Human-Led Environmental Degradation

Information on reclamation of Henry's Island for development of a brackish water fish farm was collected from secondary sources, by obtaining oral history and interviewing SFDC officials. Apart from those by comparing the Survey of India toposheet, surveyed in 1968–1969 and Landsat image of 1986, the extent of reclamation was detected (Table 11.2; Figs. 11.2 and 11.3). During PBR data collection and FGDs oral deliberations were made to find out the perceptions of the respondents on erosion of biodiversity and environmental degradation. The factors responsible for environmental degradation of Henry's Island were identified and summarised by means of primary observation. Various secondary sources reporting on environmental concerns related to Henry's Island were also cited for validation of primary observations like Paul et al. (2017), Saha et al. (2014) and Chakravortty and Ghosh (2018).

11.3 Results and Discussions

11.3.1 People's Biodiversity Register

A total of 40 flora (12 timber plants including 7 mangroves, 1 medicinal plant, 9 grasses and shrubs, 10 crops and vegetables and 8 fruit trees) and 63 fauna (8 wild and 6 domestic mammals, 13 birds, 8 insects and crustaceans, 9 reptiles, 3 snails, 10 brackish water fishes and 6 freshwater fishes) species were reported by the locals. By discussing with the officials of Bakkhali Range and SFDC and citing previous literatures (Naskar et al. 1999; Sanyal 1999; NRCWS 2003; Dey 2006; Das 2013; Sahana et al. 2001; Ghosh et al. 2011; WBBB 2020), the common names and scientific names of the species were derived and the final list of species documented during the PBR was prepared (Table 11.3).

To find out the species distribution pattern, four broad categories of land use and land cover were identified: sandy beach, mangrove swamp with mudflats and blanks, aquacultural ponds and other built-ups (settlements, embankments, etc.) (Fig. 11.4). *Phoenix paludosa*, *Avicennia* sp., *Excoecaria agallocha*, *Sonneratia apetala*, *Ceriops tagal* and *Aegiceras corniculatum* are the seven major mangrove species available at Henry's Island as reported by the respondents. The villagers make extensive use of *Phoenix paludosa*; leaves are used for thatching and fencing; fruits are sweet and edible. *Tamarix gallica*, *Acacia nilotica* and *Opuntia monacantha* are the species mainly found along the beach, planted for beach dune stabilisation, while along the inner embankments (both on Henry's Island and adjoining villages), *Acacia auriculiformis* are widely planted. In recent years *Bixa orellana* plantations are gaining popularity in the forest adjoining villages due to its commercial demand, used mainly in cosmetics and as food-colouring agent. *Azadirachta indica*, *Samanea saman*, *Cocos nucifera* and *Phoenix sylvestris* are found both inside and forest margin villages of the Island. *Aegle marmelos*, *Tamarindus indica*, *Spondias mombin* and *Ziziphus mauritiana* are the common fruit trees found in nearby villages. *Suaeda maritime* and *Suaeda nudiflora* are found on beach, especially on sand dunes, while the mangrove shrub *Aegialitis rotundifolia* is found in the mudflats and blanks. *Schoenoplectus articulates* grasses are found near the saline waters of estuaries or brackish water ponds. Grasses like *Digitaria adscendens*, *Cynodon dactylon*, *Pennisetum purpureum* and *Tripsacum dactyloides* are found

Table 11.3 Species reported by the locals during PBR documentation at Henry's Island, Indian Sundarban

Flora			
Timber plants			
Sl. no.	Common name	Local name	Scientific name
1	Mangrove date palm	Hetal	*Phoenix paludosa*
2	Indian mangrove	Bain	*Avicennia sp.*
3	Blind-your-eye mangrove	Gewan	*Excoecaria agallocha*
4	Tall-stilt mangrove	Garjan	*Rhizophora apiculata*
5	Crabapple mangrove	Keora	*Sonneratia apetala*
6	Yellow mangrove	Garan	*Ceriops tagal*
7	Black mangrove	Khalsi	*Aegiceras corniculatum*
8	French tamarisk	Jhau[a]	*Tamarix gallica*
9	Black babul	Babla[a]	*Acacia nilotica*
10	Rain tree	Kheerish	*Samanea saman*
11	Neem	Neem	*Azadirachta indica*
12	Earleaf acacia	Sonajhuri[a]	*Acacia auriculiformis*
Medicinal plants			
13	Castor oil plant	Arendi	*Ricinus communis*
Grass, shrubs and others			
14	Henry's crab grass	Sua/cheo	*Digitaria adscendens*
15	Bermuda grass	Durva	*Cynodon dactylon*
16	*Schoenoplectiella*	Motmoti	*Schoenoplectus articulatus*
17	Cactus	Phonimonosa[a]	*Opuntia monacantha*
18	Elephant grass	Bajra	*Pennisetum purpureum*
19	Gama grass	Gama	*Tripsacum dactyloides*
20	Tora	Tora	*Aegialitis rotundifolia*
21	Annual sea-blite	Nona-shak	*Suaeda maritima*
22	Seepweeds	Giria-shak	*Suaeda nudiflora*
Crops and vegetables			
23	Aman paddy	Aman dhan	*Oryza sativa*
24	Boro paddy	Boro dhan	*Oryza sativa*
25	Chitti paddy	Chitti dhan	*Oryza sativa*
26	Onion	Pneyaj	*Allium cepa*
27	Cauliflower	Fulkopi	*Brassica oleracea* var. botrytis
28	Cabbage	Badhakopi	*Brassica oleracea* var. capitata
29	German turnip	Olkopi	*Brassica oleracea Gongylodes*
30	Green pea	Matar kadhai	*Pisum sativum*
31	Bitter gourd	Uccha	*Momordica charantia*
32	Ridge gourd	Jhinge	*Luffa acutangula*
Fruits			
33	Coconut	Narkel	*Cocos nucifera*
34	Date palm	Khejur	*Phoenix sylvestris*
35	Achiote	Sindur fol[a]	*Bixa orellana*
36	Mangrove date palm	Hetal kul	*Phoenix paludosa*

(continued)

Table 11.3 (continued)

Flora			
Timber plants			
Sl. no.	Common name	Local name	Scientific name
37	Indian bael (wood apple)	Bel	*Aegle marmelos*
38	Tamarind	Tentul	*Tamarindus indica*
39	Hog plum	Amra	*Spondias mombin*
40	Indian jujube	Kool	*Ziziphus mauritiana*
Fauna			
Mammals (wildlife)			
41	Leopard cat	Baghrol	*Prionailurus bengalensis*
42	Jungle cat	Bon biral	*Felis chaus*
43	Wild boar	Buno suor	*Sus scrofa*
44	Spotted deer	Chital harin	*Axis axis*
45	Bengal sacred langur	Hanuman	*Semnopithecus entellus*
46	Indian grey mongoose	Neul	*Herpestes edwardsii*
47	Bengal fox	Khyank-sheyal	*Vulpes bengalensis*
48	Rhesus monkey	Banar	*Macaca mulatta*
Mammals (domestic)			
49	Cow	Goru	*Bos taurus*
50	Black Bengal goat	Chagol	*Capra hircus*
51	Pig	Suor	*Sus scrofa domesticus*
52	Garole sheep	Bhera	*Ovis aries*
53	Indian pariah dog	Desi kukur	*Canis lupus familiaris*
54	Domestic cat	Biral	*Felis catus*
Insects and crustaceans			
55	Giant honey bee	Moumachi	*Apis dorsata*
56	Centipede	Bicha	*Scolopendridae* sp.
57	Giant Indian hornet	Bhimrul	*Vespa mandarinia*
58	Ants	Pipre	*Formicidae* sp.
59	Water beetle	Gobra/gubre	*Laccophilus* sp.
60	Tropical carpenter bee	Bhomra	*Xylocopa* sp.
61	Red ghost crab	Lal kankra	*Ocypode macrocera*
62	Prawn	Chingri	*Dendrobranchiata* sp.
Birds			
63	Common myna	Shalikh	*Acridotheres tristis*
64	Spotted dove	Ghughu	*Spilopelia chinensis*
65	Common sandpiper	Batan	*Tringa hypoleucos*
66	House sparrow	Charai	*Passer domesticus*
67	Red-vented bulbul	Bulbul	*Pycnonotus cafer*
68	Openbill stork	Shamuk-khol	*Anastomus oscitans*
69	Heron	Bok	*Ardea* sp.
70	Bank myna	Sonamoni/gang shalikh	*Acridotheres ginginianus*
71	House crow	Kaak/pati kaak	*Corvus splendens*

(continued)

Table 11.3 (continued)

Flora			
Timber plants			
Sl. no.	Common name	Local name	Scientific name
72	Jungle myna	Moyna-pakhi	*Acridotheres fuscus*
73	Indian ring-necked parrot	Bon-tiya	*Psittacula krameri manillensis*
74	Rock dove	Payra	*Columba livia*
75	Little cormorant	Pankouri	*Phalacrocorax niger*
Reptiles			
76	Indian saw-scaled viper	Bora	*Echis carinatus*
77	Cobra	Keutia/keute	*Naja naja*
78	Chequered keelback	Dhora	*Xenochrophis piscator*
79	Common krait	Shiyalchiti	*Bungarus caeruleus*
80	Vine snake	Laudoga	*Ahaetulla nasuta*
81	Rat snake	Dharas	*Ptyas mucosa*
82	Russell's Viper	Chandrabora	*Vipera russelli*
83	Split keelback	Mete	*Atretium schistosum*
84	Tokay gecko	Takshak	*Gekko gecko*
Snails			
85	Nerite snail	Boro shamuk	*Nerita articulata*
86	Freshwater snail	Gara shamuk	*Indoplanorbis exustus*
87	Red lip nerite snail	Chapta shamuk	*Neritina violacea*
Fishes			
88	Paradise threadfin	Topshe	*Polynemus paradiseus*
89	Silver pomfret	Pomfrete	*Pampus argenteus*
90	Hilsha	Iilish	*Tenualosa ilisha*
91	Mystus	Med tangra	*Mystus*
92	Stringray	Shankar	*Himantura imbricata*
93	Bhola	Bhola	*Sciaenidae*
94	Nore bhola	Nore/nere bhola	*Sciaenidae*
95	Goby	Tul bele	*Gobiidae*
96	Chnada	Chanda	*Scatophagus argus*
97	Mudskippers	Gule/gulla	*Boleophthalmus boddarti*
98	Bata	Bata[b]	*Channa punctatus*
99	Katla	Katla[b]	*Catla catla*
100	Rohu	Rui[b]	*Labeo rohita*
101	Mrigal	Mrigal[b]	*Cirrhinus cirrhosus*
102	Kalbasu	Kalbos[b]	*Labeo calbasu*
103	Barb	Punti[b]	*Cyprinidae*

[a]Plantation
[b]Freshwater fishes

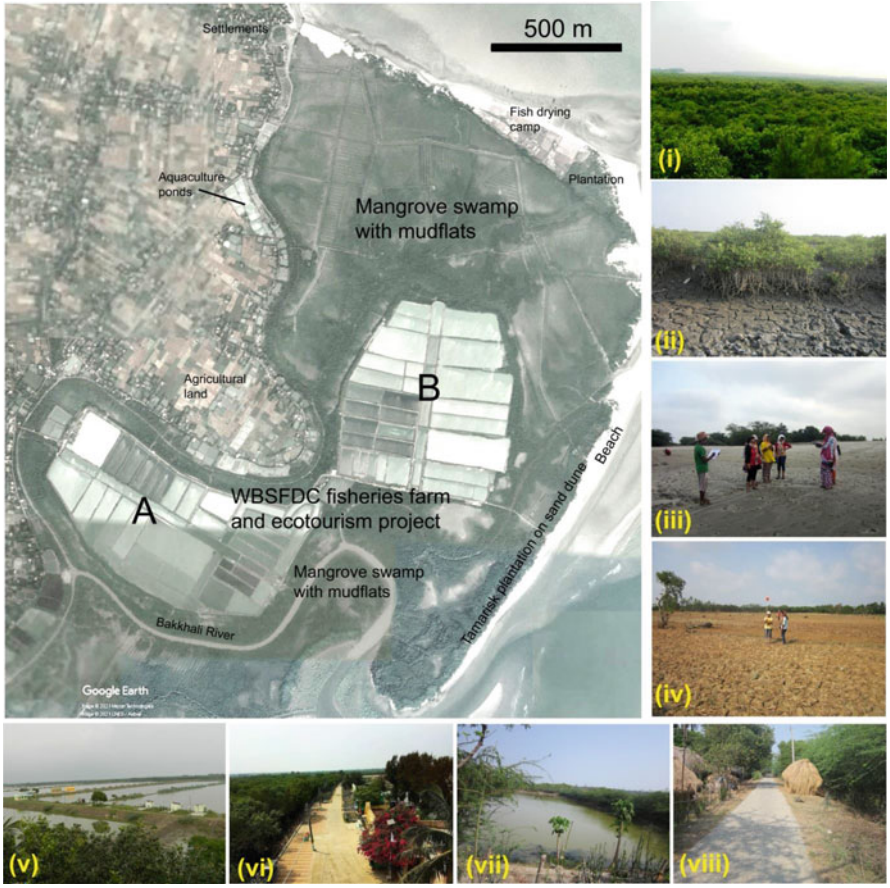

Fig. 11.4 Land use and land cover features of Henry's Island. Four broad categories are sandy beach, mangrove swamp with mudflats and blanks, aquaculture ponds and other built-ups (settlements, embankments, etc.). During 1978–1984 the West Bengal State Fisheries Development Corporation set up an aquaculture farm by clearing 149.3 ha of mangroves. The fisheries project area is divided into two sectors: Sector A (67 ha) and Sector B (40 ha). Photographs: (i) mangroves, (ii) mudflat, (iii) beach with plantation on dunes (see background), (iv) agricultural land, (v) WBSFDC fish firm, (vi) ecotourism project, (vii) aquaculture pond and (viii) settlements

in village open and agricultural fields. The medicinal plant *Ricinus communis* is found in the adjoining villages and is used for pain relieving. Apart from the above-mentioned floras, paddy and different vegetables are grown in the villages (Table 11.3).

Prionailurus bengalensis, *Felis chaus*, *Sus scrofa*, *Axis axis*, *Semnopithecus entellus*, *Herpestes edwardsii*, *Vulpes bengalensis* and *Macaca mulatta* are the common wild mammals mainly found in the mangrove swamp and adjoining areas. Besides, villagers rear common domestic mammals. Among them, garole sheep (*Ovis aries*), unique to this part of the world, demands special mention for its high prolificacy and grazing ability in knee-deep saline swamps (Sahana et al. 2001). Red crabs (*Ocypode macrocera*) dwelling on the open beach are a major tourist attraction on Henry's Island. Prawns (*Dendrobranchiata* sp.) are of high economic significance and are widely farmed in brackish water ponds. A number of common insects were also registered: *Apis dorsata*, *Scolopendridae* sp., *Vespa mandarinia*, *Formicidae* sp., *Laccophilus* sp. and *Xylocopa* sp. As found from PBR, Henry's Island houses most of the types of common snakes/reptiles found in SBR like *Echis carinatus*, *Naja naja*, *Xenochrophis piscator*, *Bungarus caeruleus*, *Ahaetulla nasuta*, *Ptyas mucosa*, *Vipera russelli*, *Atretium schistosum* and *Gekko gecko*. *Acridotheres tristis*, *Spilopelia chinensis*, *Tringa hypoleucos*, *Passer domesticus*, *Pycnonotus cafer*, *Anastomus oscitans*, *Ardea* sp., *Acridotheres ginginianus*, *Corvus splendens*, *Acridotheres fuscus*, *Psittacula krameri manillensis*, *Columba livia* and *Phalacrocorax niger* are common bird species. Besides, a number of migratory birds come in every winter. Henry's Island is renowned for aquaculture and fishing form seas and estuaries. The brackish water species as reported during PBR (including seas and estuaries) are *Polynemus paradiseus*, *Pampus argenteus*, *Tenualosa ilisha*, *Mystus*, *Himantura imbricata, Sciaenidae*, *Gobiidae*, *Scatophagus argus* and *Boleophthalmus boddarti*. *Channa punctatus*, *Catla catla*, *Labeo rohita*, *Cirrhinus cirrhosis*, *Labeo calbasu* and *Cyprinidae* are the recognised freshwater fishes. Two brackish water snails (*Nerita articulate* and *Neritina violacea*) and one freshwater snail (*Indoplanorbis exustus*) were also reported.

11.3.1.1 Identifying Human-Led Environmental Degradation

Begam et al. (2020) made a broad division of the factors responsible for degradation of small mangrove patches of SBR into environmental stressors and anthropogenic interferences. Environmental stressors include continuous erosion of the sea face due to tidal actions aided by frequent landfalls of tropical cyclones and sea level rise, increasing salinity and sulphide levels, etc. Anthropogenic interferences include expansion of agriculture and aquaculture, urbanisation and land use transformation, tourism, coastal pollution, etc (Sahana and Sajjad 2019). As noted by Paul et al. (2017), Henry's Island is highly exposed to the influences of both sets of factors. Environmental stressors are coastal erosion, storm effects, hyper-salinity and problems in mangrove regeneration, and anthropogenic interferences are forest resource use and expansion of aquaculture and tourism. In between 1969 and 2012 the coastline of Henry's Island retreated 450 m–1 km (Saha et al. 2014) and evidence of considerable numbers of saline blanks (Chakravortty and Ghosh 2018) confirms the environmental stress. But anthropogenic interferences are a far more severe threat to the mangroves and associated biodiversity, as identified by Paul et al. (2017) and also noted in this study. Traditional human use of the forest includes collection of fuelwood and livestock fodders, mangrove timbers for fixing fishing nets and hut/shack construction, mangrove leaves for thatching and fencing and extensive grazing by cattle, goats, pigs and sheep. Although the surrounding areas of

Table 11.4 Demographic changes in the adjoining villages of Henry's Island during 1951–2011 (Source: District Census Handbooks of 24 Parganas/S.24 Parganas, 1951–2011, Census of India)

Forest adjoining villages	Parameters	1951	1961	1971	1981	1991	2001	2011
Bijaybati	Total population	983	1662	1983	2639	3587	4312	4891
	Population density	203	344	410	546	742	892	1012
	% of marginal workers	–	–	–	9	28	25	30
Haripur	Total population	1577	2427	2481	4651	5939	7114	7842
	Population density	112	172	176	326	417	499	556
	% of marginal workers	–	–	–	36	29	22	37
Amrabati	Total population	1223	1599	2212	3346	4468	5565	6675
	Population density	247	324	447	770	1028	1281	1351
	% of marginal workers	–	–	–	10	4	26	25
Lakshmipur Abad	Total population	299	373	384	637	781	938	1176
	Population density	109	136	140	232	285	342	429
	% of marginal workers	–	–	–	–	–	24	30

the Island were reclaimed in between 1905 and 1922–1923 (Ascoli 1921; SoI inch-toposheet 79 C/06 surveyed in 1922–23) in spite of the traditional uses, the mangroves were not severely harmed as shown by the 1968–1969 SoI toposheet (Saha et al. 2014; Fig. 11.2). As discussed earlier, fragmentation of this mangrove patch started ~50 years ago with the establishment of the SFDC fish farm following policy decisions (Fig. 11.2). During the last ~30 years expansion of aquaculture coupled with rapid increase of population in the forest adjoining villages of Bijaybati, Haripur Amrabati and Lakshmipur Abad (Table 11.4) with high numbers of marginal workers leads to further degradation. Paul et al. (2017) identified this factor as the most influential of all other factors. One can easily identify the growth of aquaculture ponds along the forest–village boundary by completely choking the natural tidal flow of Bakkhali River (Fig. 11.4). Besides construction of mud-built walls and clay mining, sluices for fisheries, release of untreated water from fishing ponds, establishment of temporary fishing camps and fish drying platforms, oil leakage from country boats, etc. are also responsible for degradation.

Over the last ~23 years immense development of tourism has been observed here. Henry's Island marked its name on the tourism map of West Bengal as an integral part of the Fresurgunj–Bakkhali coastal tourism circuit. It attracts a footfall of thousands in terms of day travellers, especially during winter. Growth of tourism has resulted in encroachments in the form of built-ups like resorts, shacks, roads, etc. and coastal pollution and disturbances to the wildlife. Even the locals as well as officials were complaining about the irrational behaviours of the tourists during the PBR and FGDs like littering the beach by throwing plastic bottles and wrappers, chasing red crabs, illegally entering into dense jungle by ignoring prohibition, etc.

Increasing numbers of motorised vehicles and the resultant noise pollution also disturb nature. When the locals were asked about biodiversity loss, they conveyed their concerns on the decreasing numbers of leopard cats (*Prionailurus bengalensis*) and mudskippers (*Boleophthalmus boddarti*). Apart from the above issues, conservation conflicts are often reported regarding traditional use of the forest: timber cutting and forest product collection, encroachment of forest area for fishing camps, etc. (Bartaman 2018).

11.4 Conclusion

The present study has been done to document the biodiversity of Henry's Island of Indian Sundarban through PBR and to identify the threats to its bio-wealth. PBR registered 40 flora (12 timber plants including 7 mangroves, 1 medicinal plant, 9 grasses and shrubs, 10 crops and vegetables, and 8 fruit trees) and 63 fauna (8 wild and 6 domestic mammals, 13 birds, 8 insects and crustaceans, 9 reptiles, 3 snails, 10 brackish water fishes and 6 freshwater fishes) species. During PBR the traditional use of the forest and issues related to biodiversity loss and conservation conflicts were noted. Apart from major environmental stressors like coastal erosion and increasing salinity, anthropogenic interferences in the form of aquaculture and tourism seem to be the dominant factors for fragmentation (Sahana et al., 2016) of the mangroves. Bryan-Brown et al. (2020) have introduced a mangrove fragmentation metric by analysing global mangrove deforestation trends during 2000 to 2012 where four spatial patterns of fragmentation were identified: (a) low loss–low fragmentation, (b) low loss–high fragmentation, (c) high loss–low fragmentation and (d) high loss–high fragmentation (Fig. 11.5). At present, Henry's Island resembles the 'low loss–high fragmentation' (Fig. 11.5b) pattern. Anthropogenic interference, as discussed in this study, if not regulated with a proper participatory management and land use policy, will certainly lead to a 'high loss–high fragmentation' situation (Fig. 11.5d) and will result in subsequent loss of the rich biodiversity of this part of Indian Sundarban.

The UN General Assembly declared the last decade (2011–2020) 'UN Decade on Biodiversity' with the vision 'living in harmony with nature' as biodiversity loss has emerged as one of the prime environmental concerns in a warming world experiencing human population explosion. The COP-10 of UN Convention on Biological Diversity (CBD) formulated a 'Strategic Plan for Biodiversity 2011–2020' under 'Aichi Biodiversity Targets' in 2010 with an aim to achieve 20 specific targets under 5 strategic goals by 2020. But unfortunately the CBD's Global Biodiversity Outlook 5 report published in September 2020 stated that 'Biodiversity is declining at an unprecedented rate and the pressures driving this decline are intensifying' and 'the world has so far failed to halt the destruction of wildlife and life-sustaining ecosystems' (CBD 2020; WBCSD 2020). None of the 20 targets were attained, while only 6 targets were partially achieved during 2011–2020 (CBD 2020), which certainly raises worries for the sustainable future of humanity. In fact, the Living Planet

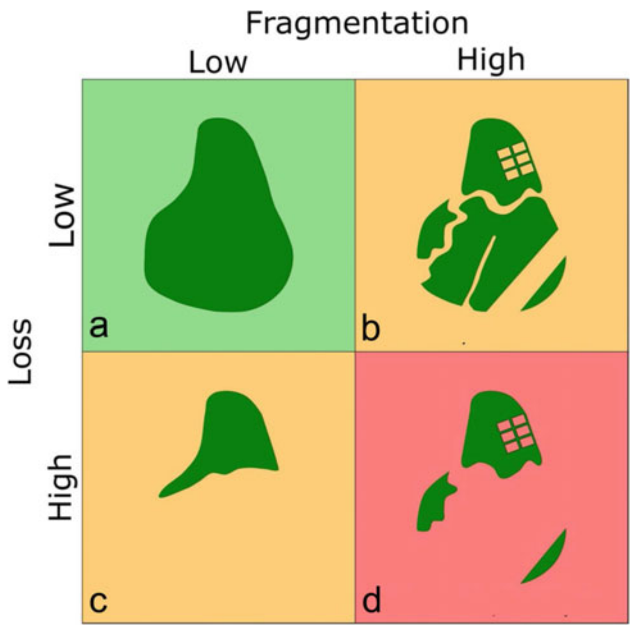

Fig. 11.5 Metric of mangrove fragmentation based on global empirical evidences of mangrove deforestation (Bryan-Brown et al. 2020). At present, Henry's Island resembles the 'low loss–high fragmentation' pattern. See text for details

Report 2020 calls for an SOS as there is a 68% fall in vertebrate species recorded in between 1970 and 2016 and presently humans are overusing the Earth's bio-capacity by ~56% (WWF-ZSL 2020). The Indian Sundarban, experiencing rapid population growth and huge anthropic pressure, isn't an exception. Lack of employment opportunities and huge numbers of marginal workers have made the situation more threatening to its biodiversity. Driven by poverty, facing losses from multi-hazard coastal events (Sahana et al. 2021) and attracted by the gains of aquaculture and tourism, human encroachment into forests continues. Between 1999 and 2019, 1005.58 ha of mangroves and 2314.04 ha of mudflats have been converted into aquaculture ponds in SBR (Giri et al. 2021). The on-paper 'ecotourism' has become a solely business-driven 'mass-tourism' in reality (Ghosh and Ghosh 2019). Additionally, both the aquaculture and tourism are controlled by politically and financially strong classes of locals or outsiders with political connections and financial resources necessary for investment, leaving little for the masses (Ghosh and Ghosh 2019; Basu et al. 2021). In the 1990s, under the Joint Forest Management scheme initiatives of creating alternative income were taken but it failed mainly because of misalignment with the cultural practices (Ghosh et al. 2015). Various studies on conservation conflicts disclose that 'bureaucratic and hierarchical structure of protected area management' considers little or no accommodation on SBR community's local demands or traditional knowledge (Ghosh 2015; Sen 2017).

All these facts reveal a large gap between theory and practice in conservation and management operations in SBR. For example, after back-to-back devastations by cyclone Amphan in 2020 and cyclone Yaas in 2021, a drive for large-scale mangrove plantation has been observed, prescribed by 'one group of outsiders' and implemented by 'another group of outsiders' like the State Forest Department and various Kolkata-based NGOs. In these circumstances, PBRs can be used, not only for documenting the bio-wealth but as a tool for discussing such issues with the commons, which will undoubtedly help in proliferating environmental awareness and in collecting baseline information for formulating a proper participatory management and land use policy aimed to reduce the gap between theory and practice.

One of the foremost limitations of the study is the extent of the study area. Although Henry's Island is a small patch of mangrove (470 ha), it represents the ongoing conservation dynamics of SBR in a nutshell. It's observed that during the last ~50 years several mangrove patches located at the margins of already reclaimed inhabited islands of SBR, like Henry's Island, have been subjected to transformations largely by anthropogenic interferences. A further investigation of some of those sites covering the whole west–east stretch of SBR may provide further insights.

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Chapter 12
Applications of Geospatial Technology on the Forest Management in Three Districts of North Bengal, India

Swarnali Mukhopadhyay and Suman Sinha

Abstract Since the creation of human life, man has learned to use nature and resources in the lap of nature and learned to protect nature unknowingly. With change in time, people progressed towards civilization. The people used the forest for their own benefit and cause of human selfishness every time has to pay the price for opposing nature at every moment. Deforestation is the result of excessive human intervention on nature. That is why there is a need for forest monitoring and management to maintain the balance of environment and nature. Geographic Information System (GIS) technology has made this task easier with the advancement of technology in recent age. ERDAS Imagine and ArcGIS software have immense importance in forest management. Any surveyed data related to any field can be accurately, proficiently, and effectively investigated with the help of recent advancement of science and technology such as GIS, GPS, and remote sensing. The study targets to investigate the prospective application of geospatial technology in forest monitoring and management of Jalpaiguri, Alipurduar, and Cooch Behar of North Bengal (Dooars) by using GIS technology. In this study, after analyzing the 20 years of satellite imagery data, it is seen that the percentage of forest area has increased and all people should be more concerned about animal roaming field to protect and reduce animal death and injury. With the dynamics of forest resources, the use of advanced geospatial technologies and forest management will continue in the future to make improved assessment, to get better productivity, and to save human power and time.

Keywords Forestry · ArcGIS · Environment · Resource · Management and monitoring · Dooars

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12.1 Introduction

Forest is closely associated with human life since ancient times. From that primitive age, wild animals have evolved with human beings in the lap of nature. Their livelihood depends on forests. From those primitive times to the twenty-first century today, humans have not been able to deny their dependence on forests. People have chosen forest to provide them food, clothing, and shelter. With the change of age, man has evolved, from the primitive state to the age of science and technology. Humans have been dependent on nature from the birth of creation so the triumph of science has occurred in the bosom of nature.

Forest management is a part of forestry dealing with the overall administrative, physical, economic, and social aspects and development, care, and protection of forest. Management of wildlife, forest resources, forest cover, and forest tourism, forest protection, and forest conservation are all included in forest management and monitoring techniques. Forest trees with herbs and shrubs all provide timber, food, medicines, fuels for human, and shelters for wildlife habitat (Sinha et al. 2011). A few decades ago, due to timber production worldwide forest cover gradually disappeared day by day; people were not concerned about the sustainability of forest resource management. Deforestation is the main problem in those decades. The sustainable development of forest resources, forest ecosystem, and forest biodiversity is the basic concept of forest management. Every country, state, and administrative body have some own rules and regulations for management and monitoring of forest. That is why various approaches of forest management are adopted according to forest utilization, forest types, and forest functions. In the present era forest monitoring and management is being done through new geospatial technology (Sinha et al. 2019).

Now the questions are: What is geospatial technology? How is this technology applicable to forest monitoring? Which method belongs to this technology? Geospatial technology refers to all of the technologies used to obtain, operate, and accumulate geographic information. Geographical information system (GIS) is one form of geospatial technology. GPS remote sensing is also part of this technology. GIS is an essential tool for forest management and monitoring from few decades ago. It is widely used for decision and policy making in the context of environmental and forest monitoring and management (Upadhyay 2009; Sharma et al. 2013). GIS and remote sensing technology are the dominant technologies used by the forest administrative body to trace any record and to investigate and to make any strategy of forest area. Where it is not possible to directly monitor the forest, the most advanced and powerful technologies used are remote sensing and GIS. The popularity of these technologies is gradually increasing in resource management, especially in the forestry sector (Sinha et al. 2021).

Due to advancement in GIS, GPS (global positioning system), and remote sensing, the method of field data collection and investigation has become easier and hassle-free in recent years (Sonti 2015). The natural forest resource policy modeling has been developed to improve (Balenovic et al. 2011; Balenovich 2012) forest inventory and management (Mozgeris 2008) planning with the help of geospatial technology. GIS helps in organizing data, understanding spatial relationships between attributes, and analyzing and creating information (Sinha and Sharma 2013; Aronoff 1989). Timber harvest, replantation, forest fertilization, conservation of plants, animals and fire management, forest productivity, forest damage, species distribution, and protection and conservation of endangered species (Vegas 2020) all are possible with the advancement of geospatial technology. The technology provides information related to the overall vegetation vigor (Sinha 2021). GPS which is known as global positioning system is also an essential tool for monitoring forest. Fire control and prevention, wildlife monitoring and management, animal corridor, roaming field, and movement of wildlife can be determined by GPS (Gikunda 2020). According to Ayhan et al. (2004), GPS is an elegant instrument that works as a ground navigator which is connected to satellite which has the ability to accurately and precisely determine locations on the Earth's surface. It has provided data of latitudinal and longitudinal location of the Earth's surface and also provided a vast data of forest like land cover area, distribution of forest boundary, and location of animal roaming field. Anon (2015) depicted the integrated utility of GIS, GPS, and RS technologies involving a wide spectrum of applications and complexities. Integrated use of multi-sensor satellite technology has been observed to produce more accurate results than the use of single sensor data (Sinha et al. 2020). General process of data collection from forest field, data query, data view, any map creation, and making any future planning related to forest are all included in this system. GIS integrates geographic and numeric data and establishes spatio-temporal dimensions in forest management (Sinha and Santra 2019). In 1980, North America, i.e., US forest service, tried to include geospatial technology in their forest management (Kane 1997). In Canada, GIS technology is implemented for forest management, to create forest inventory and timber processing (Aronoff 1989). Satellite images were used to bring up-to-date real-time data which is used to create current maps of particular forest zone. GIS-integrated simulation models serve as reliable tools for forest fire management and monitoring (Sharma et al. 2012). According to Weinstein et al. (1997) many scientists and forest researchers are very much knowledgeable in the field of geospatial technology to detect and to predict about forest fire by using high-resolution satellite imagery with the help of integrated geospatial modeling. Geospatial techniques integrating the procurement of synoptic satellite imagery are robust and powerful tools in forest monitoring where various geographically referenced information are apprehended, handled, analyzed, and presented in a single GIS framework (Zhang et al. 2006; Sinha et al. 2015).

12.1.1 The Objective of the Study

1. To determine the change detection of forest cover area by using geospatial technology in the years 2000 and 2020
2. To determine the area of vegetation density in the year 2020

3. To determine the animal roaming field with the advancement of geospatial technology in the year 2020

The current study was conducted to investigate the significance of geospatial technology for forest management and supervision in three districts of Dooars region and the techniques of monitoring the study area by using GIS and remote sensing. This study is important which is prepared by using current data of satellite image of 2020 to detect the changes of forest cover area and vegetation density. Previous research work and literature depicted the land use, land cover changes of Dooars region (2017), and animal-human relationship of Dooars region (2018). This study identified the changes of land cover area and forest density of three districts of North Bengal in the last 20 years and also identified the current position of animal roaming area.

12.2 Study Area

The study area of this research work has been selected to cover the vast forest zone of three districts, that is, Jalpaiguri, Alipurduar, and Cooch Behar of northern West Bengal of north-eastern India, which is surrounded by Bhutan in the northern side, Nepal on the western side, Bangladesh in the southern portion, and Assam in the eastern side (Roy and Sukumar 2015). The total geographical forest area of three districts is 9614 sq.km. The latitudinal extension of this area is 26° 00” N to 27°00” N and longitudinal extension is 88° 25″ E to 88° 45″ E. These zones are situated at the foothills of the Eastern Himalaya (Mukerjee 2016); this zone is known as Dooars (the meaning of the word Dooars is entrance or gateway of the hilly region of North Bengal, Bhutan, Sikkim, and north-eastern states). Dooars is alluvium- and sediment-rich floodplain land and part of lower Ganga plain (Sen 2018), which is very fertile. The main attraction of this zone is the wide dense natural forests with wildlife sanctuaries and vast green tea gardens. Main land use types of the study area are cultivation and forest and tea plantation. The natural vegetation of Dooars is a mixture of tropical evergreen, moist forest with grassland and deciduous forest (Areendran et al., 2020; Roy and Sukumar 2015), where sal, teak, peepul, sishu, bamboo, etc. are the dominant species. The climate of the Dooars region is damp and warm, which helps in the high growth of tropical moist and evergreen forests. This zone has three national parks (Gorumara, Jaldapara, Buxa), two wildlife sanctuaries, (Chapramari Wildlife Sanctuary and Buxa Tiger Reserve) and other forest areas like Chilapata & Hasimara near Alipurduar (Plates 12.1 and 12.2). There are mesmerizing and very rich diversity of plant and animal species found in Dooars forest zone, as well as numerous widespread and endangered species (Bhattacharyya et al. 2013). There is an existence of approx. 200 hamlets within the peripheral areas and inside the protected areas (Mukherjee 2016) (Fig. 12.1).

The topography of this area is partly flat to undulation, the average height of this area is 50 m to 150 m, and the slope of the area is from north to southward direction.

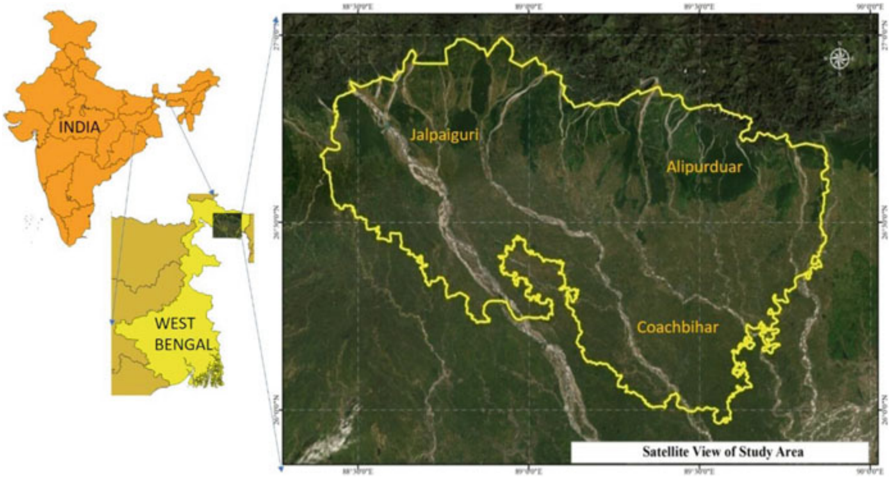

Plate 12.1 Animal roaming and forest area of Jaldapara, Jayanti Forest (1 to 4); Buxa Forest area (5 and 6) (photographs taken during survey)

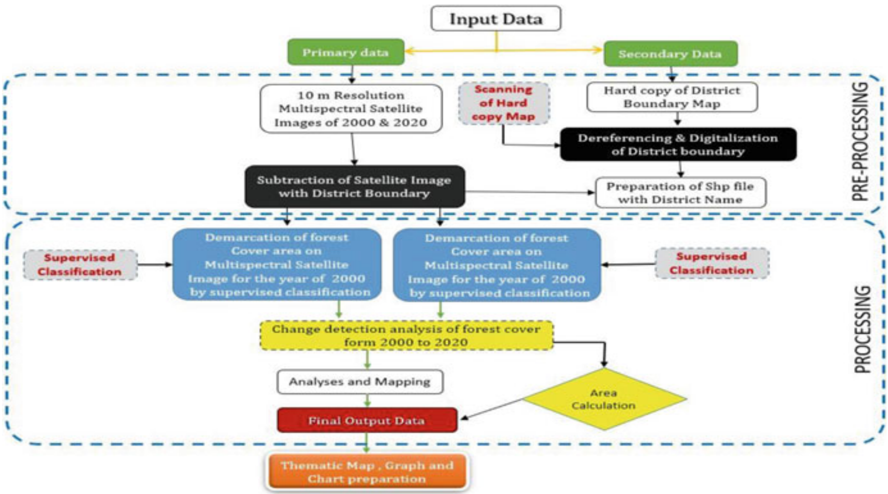

Plate 12.2 Forest area of Chapramari, Buxa, Sukna, Lataguri, Gorumara, and Chilapata (photographs taken during survey)

This area is dissected by the channels of tributaries and distributaries of Ganga and Brahmaputra. The tributaries of the Himalayan streams, like the Mahananda, the Teesta, the Sankosh, and the Jaldhaka, flowing in the region suffer frequent shifts in their channels. Rivers Lish, Gish, Murti, and Diana are nourished with rainwater (Dhali et al., 2020). Every year a catastrophic flood occurs in this area. Climatic condition varies frequently within short distance. A calm, cool, dry weather is experienced from the months of November to March. The temperature of winter

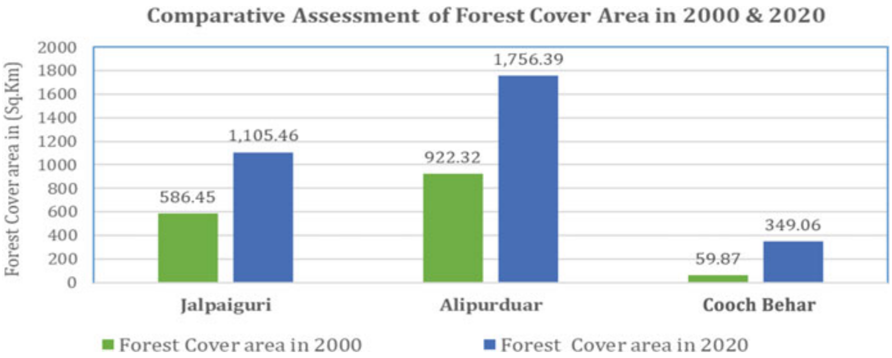

Fig. 12.1 Location map of the study area

season is 10 °C to 17 °C, and the coldest month is January. The average temperature of summer is 28 °C to 32 °C. April and May are the hottest months of this region. The average rainfall of this region is 250–400 cm.

12.3 Methodology

The development of remote sensing technology improves the availability of high spatial and high spectral resolution data from extensive range of sensors (Michael et al. 2017). Hyper-spectral imageries provide better discrimination of forest cover and any other forest physiological characteristics. Geospatial applications are being developed that infiltrate the forest canopy to reveal features of the forest bottom (Fraser et al. 2000). Researchers can use geospatial technology to gather any information about forest resource inventory, forest planning, and forest policy (Bettinger and Wing 2004). Multiresolution remotely sensed imagery has the ability to generate appropriate and perfect maps of forest composition and structure (Culvenor 2003). In India the first effort to classify forest cover categories by digital classification of satellite data was made in 1978 for Nagaland (Kushwaha et al. 1979), demarcating temperate evergreen, tropical evergreen, tropical semi-evergreen, tropical deciduous, bamboo, and degraded forests, shifting cultivation and permanent cultivation. After acquiring the data from field survey, it should be georeferenced for data accuracy, which can be located on the imagery (Sudhakar et al. 1999). The present study is conducted to detect forest area cover of the three districts of North Bengal (Jalpaiguri, Alipurduar, and Cooch Behar). Maximum toposheets of the three districts are restricted and unavailable. Only three toposheets that are 78B/14, 78F/7, and 78F/11 of R.F 1:50000 are available to study this area. Satellite imageries from the Indian Remote Sensing Satellites which are the main sources of data to assess the accuracy of forest information in the years 2000 and 2020 (Table 12.1), registered to UTM zone 45 N projection and WGS 84 datum,

Table 12.1 Different satellite images for detecting forest resource data

Sentinel-2B satellite image 2020		IRS-1C LISS-III satellite image 2000	
Bands	Spatial resolution (m)	Bands	Spatial resolution (m)
Band 2 – blue	10	Band 1 – blue	23.5
Band 3 – green	10	Band 2– green	23.5
Band 4 – red	10	Band 3– red	23.5
Band 8 – NIR	10	Band 4 – NIR	23.5

have been used for the study (McGarigal et al. 2012). IRS-1C LISS lll satellite image is used to extract forest data in 2000 based on 23.5 m spatial resolution (Bands 1, 2, 3, 4), which is very effective in mapping forest vegetation types and land cover of forest of three districts of North Bengal (Roy 2011). Sentinel 2B Satellite Image is used to assess the forest cover in 2020 with 10 m of spatial resolution (Bands 2, 3, 4, 8). This is a very new (2017) multispectral sensor quality image which is used for the management and monitoring of forest of various plant indices. All image processing has been carried out using the ERDAS Imagine 13.0 which is a remote sensing software, GIS software ArcInfo 10.2, and data construction software Global Mapper 18. The satellite images of the years 2000 and 2020 were georeferenced and digitized by using remote sensing software. After conversion of shp. file, the images delineated the forest cover area in the years 2000 and 2020 using supervised classification with maximum likelihood algorithm (Sinha et al. 2013) to detect the change of forest cover area and classify them by very dense forest, moderately dense forest, open forest, and scrub on the basis of the extent of vegetation cover. Change detection is a very useful and vital tool for monitoring and managing forest resources (Macleod and Congalton 1998). As some sensor open-source satellite data are not available, data from different sensors are used for change detection analysis. Before classification of satellite image, resampling and calibration of the satellite data into the same spatial resolution have been done.

Animal roaming field in forest area of three districts was detected by GPS (during field survey) with the help of satellite imagery. Ground survey was conducted in these locations for confirmation of the animals' presence through detection of muck heaps, footprints on the moist soil or mud, etc. GPS points were taken on these areas and maps have been created (Roy and Sukumar 2015). Literature about animals roaming in this area was reviewed (Wildlife Institute of India (1995–1997). Local People of this forest area are dependent on the forest for timber, fuel, and other forest resources. They were the target group to collect primary data through interview (questionnaire method); they had given information about the nature of forest; forest fire; human-animal conflict; animal poacher; and location, time, and presence of animals and their roaming field. Fifteen to 20 villagers of each village nearer to each forest area (Gorumara, Chapramari, Buxa-Jayanti, Jaldapara, Lataguri, Cooch Behar) were randomly selected for this study, and the final sample size was 110 villagers. Other sources of data are collected by field survey, laboratory analysis, study

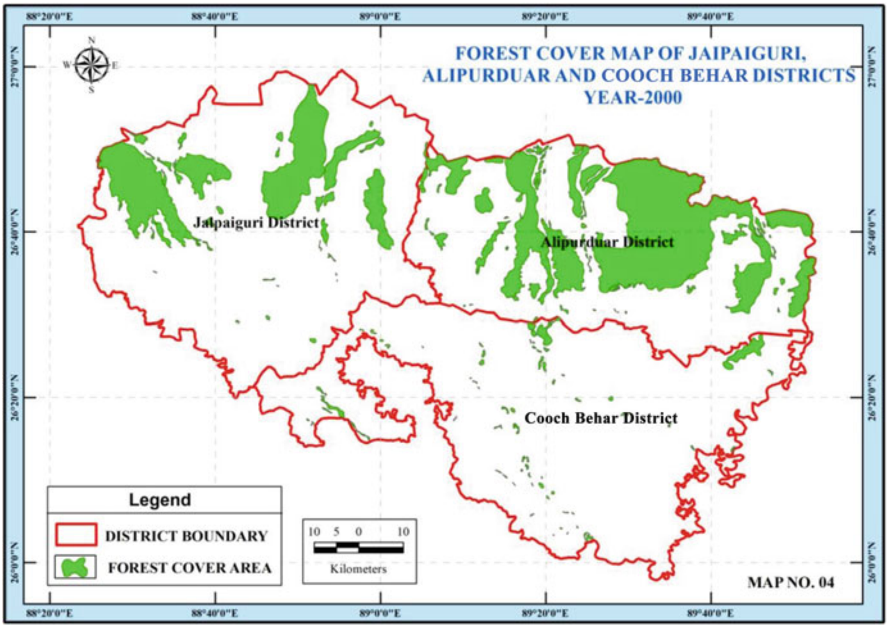

Fig. 12.2 Flowchart

map, previous literature, etc. In-depth interview of forest officers improves the validity and reliability of the collected data (Fig. 12.2).

12.4 Result

It is detected that the forest area of the above-said study area has shown a significant change in forest area. The total geographical area of three districts is 9614 sq.km, whereas Jalpaiguri is 2844 sq.km, Alipurduar is 3383 sq.km, and Cooch Behar is 3387 sq.km. The total forest cover area of Dooars region in the year 2000 is 1568.64 sq.km (forest cover area in Jalpaiguri is 586.45 sq.km, in Alipurduar is 922.32 sq.km, in Cooch Behar is 59.87 sq.km), and in the year 2020 the total forest cover area is 3210.91 sq.km (in Jalpaiguri 1105.46 sq.km, in Alipurduar 1756.39 sq. km, and in Cooch Behar 349.06 sq.km.). In the year 2000 the distribution of the total forest cover area to the geographical area is 16.32% (Jalpaiguri 20.62%, Alipurduar 27.26%, and Cooch Behar 01.77%), and in the year 2020 the distribution of total forest cover area to geographical area is 33.40% (Jalpaiguri 38.87%, Alipurduar 51.92%, and Cooch Behar 10.31%). The total percentage of forest cover area has grown during the years 2000 to 2020 to +17.08% (Jalpaiguri +18.25%, Alipurduar +24.65%, Cooch Behar +08.54%) (Figs. 12.3, 12.4 and 12.5). A comparative assessment depicts that the increasing rate of forest cover area of Alipurduar is

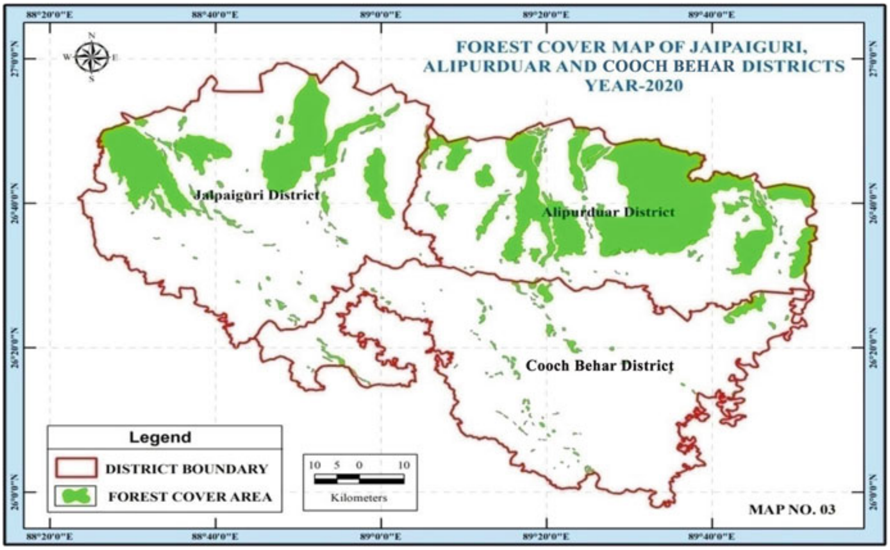

Fig. 12.3 Bar graph showing the comparative assessment of forest cover area

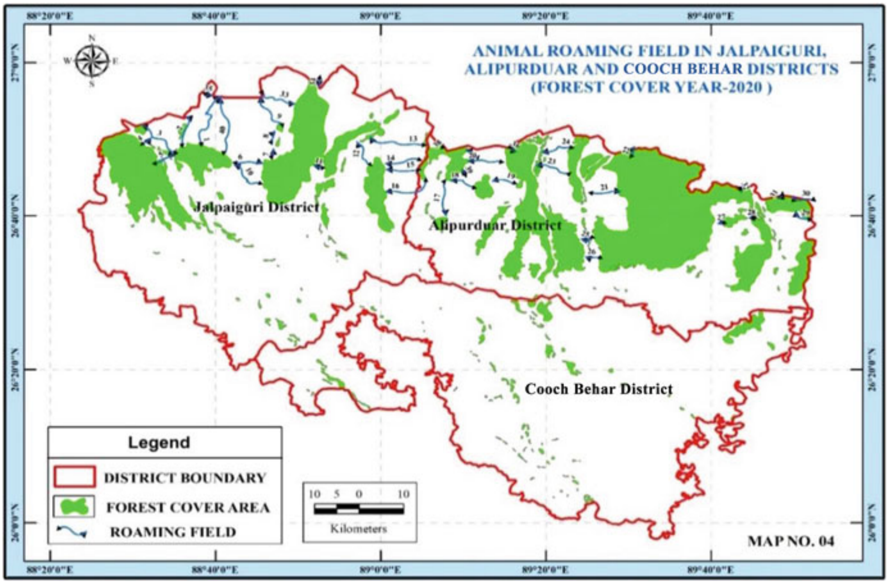

Fig. 12.4 Forest cover area map (2000)

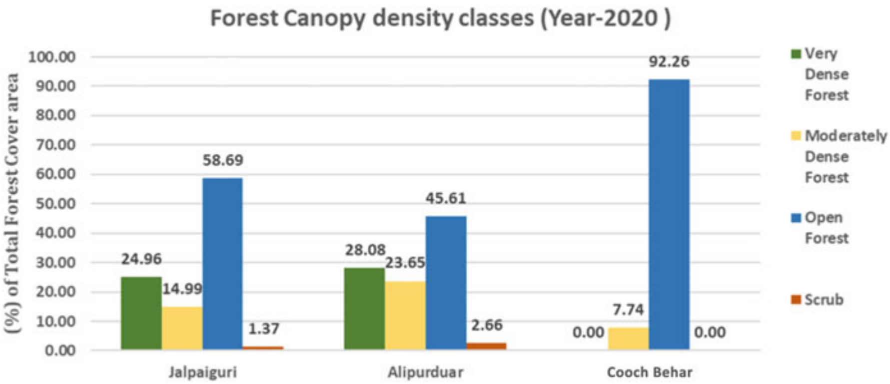

Fig. 12.5 Forest cover area map (2020)

more hopeful in the last 20 years than of Jalpaiguri and Cooch Behar. Gradually increasing urban areas, settlements, and deforestation are the main causes of less growth of forest area in Jalpaiguri and Cooch Behar. But on the whole, it is proved that forest cover area has grown gradually in the last 20 years, which is detected due to the advancement of geospatial technology (Table 12.2).

In a joint project between Forest Department and Department of Environment West Bengal State Government and their proper management, the forest cover area in three districts of North Bengal is significantly increasing in the last 20 years. Efforts are being made to prevent the death of wild animals and birds by perfect monitoring and supervision and using advanced geospatial technology. Forest cover area has increased owing to the cutting down of trees in a proper and regulated way as per requirement and planting new trees to replace these forest trees and by the method of controlling the forest fire by using remote sensing technology.

Another branch of forest management and monitoring processes is conservation of wildlife (Sinha 2020). This forest zone is very rich in various plant species with wide-ranging animal diversity of endangered species (Jain et al., 2021). Elephant, rhinoceros, one-horned rhino, leopard, deer, sambar, peacock, monkey, bison, and Indian fox are almost visible in the road-side area of North Bengal. Some important highways, road connections, and railway tracts are found in the animal roaming zone which may cause wildlife death and injury. To protect the valuable wildlife from death and injury and to avoid human-wildlife conflict, it is very essential to detect animal roaming zone (Saha and Datta 2017). Animal roaming field and animal corridors were detected by GPS and using geospatial technology. There are 40 roaming fields detected (Roy and Sukumar 2015). Some of the roaming fields were identified during field survey (with GPS) and some were with the help of data from the Forest Department.

Remote sensing techniques have been used to separate various types of forest density classes in Jalpaiguri, Alipurduar, and Cooch Behar districts of North Bengal (Sudhakar et al. 2007). Forest classification has been detected by using GIS software (Midha and Mathur 2010). It is found that in Jalpaiguri district very dense forest cover area is 24.96%, area of open forest is 58.69%, area of moderately dense forest

Table 12.2 Assessment of forest cover area

Assessment of forest cover area using remote sensing and GIS techniques							
SI no.	District	Geographical area in (sq. km)	Forest cover area in 2000 (sq. km)	Forest cover area in 2020 (sq. km)	(%) of total geographical area (sq. km) – 2000 (%)	(%) of total geographical area (sq. km) – 2020 (%)	(%) of forest cover area growth during 2000 to 2020 (sq. km.) (%)
1	Jalpaiguri	2844.00	586.45	1105.46	20.62	38.87	+18.25
2	Alipurduar	3383.00	922.32	1756.39	27.26	51.92	+24.65
3	Coach Behar	3387.00	59.87	349.06	01.77	10.31	+08.54
Total		**9614.00**	**1568.64**	**3210.91**	**16.32**	**33.40**	**+17.08**

Fig. 12.6 Animal roaming field in forest area of North Bengal (2020)
Source: Computed from Field survey, GPS study, Forest Department and Research Article of Roy and Sukumar 2015

is 14.99%, and scrub area is 1.37%. In Alipurduar the area of very dense forest is 28.08%, area of moderately dense forest is 23.65%, area of open forest is 45.61%, and scrub is 2.66%. In the district of Cooch Behar the area of open forest is 92.26% and moderately dense forest is 7.74% but the area of dense forest and scrubs are nil (Fig. 12.6 and 12.7) (Table 12.3).

Fig. 12.7 Forest density classes

Table 12.3 Percentage of forest density classes

Assessment of forest cover area using remote sensing & GIS techniques			Forest canopy density classes (%) of total forest cover area			
SL No.	District	Forest Cover area in 2020 (Sq.km)	Very Dense Forest	Moderately Dense Forest	Open Forest	Scrub
1.	Jalpaiguri	1105.46	24.96	14.99	58.69	1.37
2.	Alipurduar	1756.39	28.08	23.65	45.61	2.66
3.	Cooch Behar	349.06	0.00	7.74	92.26	0.00
Total		3210.91				

Source: Forest survey of India published report (forest Density Classes).

12.5 Discussion

An extensive variety of scientific research has been done from the last two to three decades about forest research (Coppin and Bauer 2009) with the gradual advancement of geospatial technology to protect forest resources, forest ecology, and forest diversity with the help of the Government and Forest Department in Dooars region. After reviewing the wide variety of research articles, it proves that each of them has brought a different level of research. The advancement of modern geospatial technology in forest research is becoming more and more progressive day by day. Sudhakar et al. (1999) depicted that GIS and remote sensing are dominant design technologies with digital records and monitoring tools for forest management in these regions like identifying physiography, forest soil types, geology forest vegetation types, forest products, forest fire, and forest poacher. Sonti (2015) described that forest researcher should prepare various types of map to assist in monitoring and management of forest resources like forest plantation, forest species, forest neighbor (depended on forest resources), forest topographical features, distribution of any features like rivers, water point, road, etc (Ahmed et al., 2017). Forest fire is a very harmful and common disaster in dry season in wide forest range; according to (Sahana and Ganaie, 2017) forest mapping is essential to prevent fire and to protect wild animal and forest vegetation. According to Chuevieco et al. (1989) the GIS-based model is very effective in preparing a plan for forest fire management to protect recreation values of forest and wildlife habitat. Wulder and Franklin (2007) stated that gathering of forest records, monitoring, and management are not very easy. Geospatial technology can modify management activities by mingling models to forest researcher. They used satellite image and aerial photography to depict the methodology of geospatial technology. According to Merry et al. (2007) geospatial technology is a vital technology for envisioning and understanding the communication of spatially distributed forest resources and used a newer technology that is Integrated Mapping Technique (IMT), which is capable of acquiring three-dimensional spatial information from the field. According to Selvarajan et al. (2009) the various types of technologies they used are Airborne LiDAR, land-based

Table 12.4 District-wise area under forest in Dooars

Forest cover	Districts			West Bengal (sq. km)	India (sq. km)
	Jalpaiguri (sq.km)	Alipurduar (sq.km)	Cooch Behar (sq.km)		
Reserve forest	1483	975	------------	7054	423,311
Protected forest	217	92	42	3772	217,245
Unclassified state forest	90	----------	15	1053	127,881
Total forest area	1790	1067	57	1187	768,437
Total geographical area	6227	3136	3387	88,752	3,287,240

Source: State Forest Report of West Bengal (2011-12) Govt. of India

Table 12.5 Forest areas of North Bengal

Protected area		
Wildlife sanctuaries	Districts	Area in sq. km
Mahananda	Darjeeling	158.04
Chapramari	Jalpaiguri	9.60
Buxa	Alipurduar	267.92
National park		
Neora	Darjeeling	88.00
Buxa	Alipurduar	117.10
Gorumara	Jalpaiguri	79.45
Jaldapara	Alipurduar and Cooch Behar	216.5
Reserves		
Buxa Tiger Reserve	Alipurduar	370.29
Elephant Reserve (Eastern Doors)	Alipurduar	977.51

Source: Computed from State Forest Report of West Bengal (2011-2012) Govt. of India

LiDAR, IMT, aerial videography, and terrestrial videography to acquire resource data from the ground. In recent age the most innovative and advanced technology for collection of forest resource data is the use of drones. Applications of geospatial technology and using drones provide evidence of the present scenario of forest cover and the presence of wild animals. Most advanced techniques such as artificial intelligence (AI) and machine learning (ML) models are used for detection and segmentation and for forest mapping and monitoring using satellite and drone data. Drones can be used for various forest related technological applications like tree counting, assessment of tree diameter and tree height, forest cover mapping, forest type classification, density classification, and change detection all technological applications followed by drone data. But it is a very expensive and time-consuming process to use drone to collect forest data. In my study I could not apply this advanced technology for this reason (Tables 12.4 and 12.5).

To make my studies fruitful I have consulted various types of books, articles, papers, forest reports, etc. As can be seen from the State Forest Report of West Bengal (2011–2012), reserve forest cover area is 1483 sq.km, protected forest area is 217 sq.km, and unclassified forest area is 90 sq,km in Jalpaiguri; reserve forest is 975 sq.km and protected forest area is 92 sq.km in Alipurduar; and protected forest area is 42 sq.km and unclassified forest area is 15 sq.km in Cooch Behar. The area of protected wildlife sanctuaries is 9.60 sq.km in Jalpaiguri (Chapramari) and 267.92 sq.km in Alipurduar. The area of national park is 117.10 sq.km in Buxa (Alipurduar), 79.45 sq.km in Gorumara (Jalpaiguri), and 216.5 sq.km in Jaldapara (Alipurduar and Cooch Behar). The area of Buxa Tiger Reserve (Alipurduar) is 370.29 sq.km and Elephant Reserve Forest (Alipurduar) is 977.51 sq.km.

In this study I have been able to show how forest management and monitoring can be done using advanced geospatial technology. I want to unfold changes of forest cover area in the last 20 years and also detect the wildlife grazing field and classification of vegetation density. Advanced technologies can improve forest management and monitoring in this region but it lacks advanced equipment; the sentiment of local people is an obstacle in the way of moving forward. I had to also face some problems while doing this work. There have been some limitations to do the work forward in terms of collecting and gathering of some information. Collecting spatial data, organizing the data for GIS use, and recording these processes are usually the most expensive and time-consuming (Wing and Bettinger, 2003; Lo and Yeung, 2002) components of any GIS project. Some of the data were inaccessible in Government and administrative departments like forest and irrigation due to restrictions to public use. One of the important study materials is toposheet analysis, but some of the toposheets are even restricted and unavailable. Another aspect is that advanced geospatial technology is very new for forest management in this area, and a lack of a geospatial technologist is also a barrier of research work. Hence, literature-based analysis has to be a reliable source for the continuation of this research work. Remote sensing data has been used for screening forest cover variation in Dooars which has certain restrictions; some toposheets of the study area also restricted for any research work; some areas are very difficult to organize without the help of a widespread field survey. The considered location of the study area and strict forest guidelines and principles are the other restrictions which have been faced by the researcher during the field study as well as during the collection of secondary data (Sen 2018).

12.6 Conclusion

The present study evaluated the feasibility of using geospatial technology to protect forest resources. It indicates that new advancement of technology can demonstrate the potential ground-based information, related to forest management and monitoring. Progresses in large bandwidth and web-based equipment will deliver much better prospects for data access even in more remote areas. Geospatial data from any field area provide real-time accurate digital data to the planners and researchers about various forest related aspects like the forest canopy density identification, counting of forest trees, measuring of leaf sizes, forest fire spots and extents, forest diseases, nature of wild habitats, etc. that provides accurate information for future forest-related designs and planning. The current remote sensing technology and GIS can predict the destruction of forest resources like precious forest species of flora and fauna. In the earlier times forest monitoring was very difficult due to real ground survey in Dooars region, but in the present day with the help of satellite imageries, RS, and GIS, many forest-related problems have been solved. It is now possible for local people to predict wild animal interaction which may cause property and crop damage and livestock predation, and attacks of these animals on people can result in deaths and injuries (Brandon et al,1998). Human-animal conflict is one of the major problems in forest locality which may both hamper the wild animal conservation and also affect human social, cultural, and economic life. So forest monitoring through geospatial technology is very essential for future planning for forest resource conservation. This research will be much more acceptable to policy maker by analysis of extensive field survey through drone data.

The current study specifies the applications and significance of remote sensing technology for forest resource monitoring. Satellite positioning systems have a significant role in enhancing forest investigation actions. This study depicts the changes of land cover area of three districts of North Bengal in the last 20 years. Increasing rate of forest cover area demonstrates the effectiveness of forest conservation procedures that protects the forest biodiversity and ecosystem. But sometimes human activity, free traveling in the forest area, and the presence of animal poacher destroy the biodiversity and forest ecosystem. So more advanced tools and high-resolution data are necessary for the protection of forest resource because forest is a dynamic resource. Consequently, this study has tried to focus on an outline of the present state of geospatial technology and its potential in natural forest resource management and as a forest management tool for natural resource concerns. Based on this study finding it is recommended that the Forest Department of West Bengal should develop infrastructural development on geospatial technology for forest ecosystem and forest conservation.

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Part IV
Forest Monitoring Using GIS and Remote Sensing

Chapter 13
An Assessment of the Temporal Changes in Land Cover and Forest Fragmentation Using Geospatial Techniques: A Case Study from the Central Indian Highlands

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Abstract The present study was carried out in the districts of Mandla and Hoshangabad, in Madhya Pradesh, India. These two districts have sizeable areas under deciduous forests. Given the high dependence of tribal communities on these forests, it is essential to characterize the land use and the status of vegetation in these districts. Land use and land cover (LULC) maps were prepared for landscape characterization for two different time periods (2000 and 2017). The area was classified into eight classes, i.e. dense forests, scrub forests, open forests, agricultural lands, water bodies, fallow lands, built-up areas, and open/sandy areas. The assessments show that dense forest areas have increased in both districts. However, this was not reflective of increases in true forests. For instance, forests in Mandla have been converted to monoculture stand of *T. grandis* (~83%). Since 2000 Mandla and Hoshangabad have lost 8.73% and 6.43% of their open forest areas, respectively. Expansion of agriculture and built-up areas is common at both sites, occurring at the cost of ecologically important land cover types such as scrub forests and open areas/sandy areas primarily as riverbeds. Results from change detection in forest cover and other land use classes show that compactness of open and scrub forests has reduced whereas patchiness has increased. Patches in close proximity to the forest edges will be vulnerable to edge effects and encroachments. The areas under dense forests have increased, while the number of patches and edge density has decreased. However, this has occurred owing to the existing gaps inside the dense canopies deep inside the forests being replaced by plantations resulting in an increase in contiguity. Although some dense canopy areas were seen to be rich in moisture content based on high

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NDMI values, large forest areas were under moisture stress. Emphasis has to be given to maintaining heterogeneity in species composition within the forests as well as to avoid fragmentation.

Keywords Deciduous forests · Landscape characterisation · Forest fragmentation · Central India

13.1 Introduction

The rise in human population, the expansion of settlements, and the resulting increase in the demand for food and animal fodder have led to an increase in the demand for land. One of the frequently preferred options is to compromise forest lands. In recent times, accounting of natural resources and the ecosystem services provided by natural ecosystems are gaining popularity (Acharya et al. 2021; Yang et al. 2021; Zhang et al. 2021; Hussain et al. 2020). The idea also gains currency from the fact that during the pandemic (2020–2021), of the three major sectors of economic activity in India, namely, agriculture, industry, and services, only agriculture clocked a positive growth rate of 3.4%, whereas the other two contracted 9.6% and 8.8%, respectively (Economic Survey, 2020– 2021). In India, the activities allied to agriculture include three subcomponents: (i) livestock, (ii) forestry and logging, and (iii) fishing and aquaculture. The average contribution of the second subcomponent forestry and logging to the GVA (gross value addition) during 2014–2019 was 1.44%. Recent times have seen a rise in the interest in valuing natural capital and ecosystem services (Acharya et al. 2021; Yang et al. 2021; Zhang et al. 2021; Hussain et al. 2020). Many studies have also been carried out at global, national, and regional levels emphasizing the contribution of forests to livelihood generation (Miller and Hajjar 2020; Adam et al. 2013; Singh et al. 2010; Bhattacharya and Prasad 2009; Shah and Sajitha 2009; Quang and Nam Anh 2006; Paumgarten 2005; Shackleton and Shackleton 2004). Nonetheless, forest clearance has been rampant and isolated patches of forest are often cleared to make way for settlements and agriculture. This highlights the need to monitor forest cover and other land uses at regular intervals to maintain a balance between development and rejuvenation of natural resources.

Over time, different techniques have been developed to assess land cover. Prior to the use of satellite imagery, ground studies such as enumeration of vegetation were used to assess the nature and extent of forest cover, whereas land surveys were used for studying the different land use types. These activities were laborious and time-consuming. With the advent of remote sensing, such land cover studies could be conducted relatively rapidly and easily and with a high degree of accuracy (Choudhary et al. 2021; Solanki et al. 2019). Mengistu and Salami (2007) from south-western Nigeria; Dewan and Yamaguchi (2009) from Greater Dhaka, Bangladesh; Areendran et al. (2013) in Madhya Pradesh, India; Sharma et al. (2016) from Sikkim, India; and Solanki et al. (2019) in Kerala, India, have used geospatial analytical techniques to assess spatio-temporal changes in land use in their respective study areas. These studies document that non-forested land use types are expanding at the cost of forests, water bodies, and wetlands. Population growth, unplanned economic expansion, and increased demand for infrastructure were some of the reported factors responsible for such land conversions. The dynamic socio-economic conditions of developing countries have led to far greater changes in land use and land cover (LULC) than in developed countries (World Bank 2007).

Large tracts of natural forests worldwide are undergoing fragmentation, resulting in the formation of smaller and isolated patches. Multiple studies have shown that forest fragmentation has increased with time (Padalia et al. 2019; Sharma et al. 2016; Armenteras et al. 2003; Noss 2001; Gibson et al. 1988). In India, nearly all major biogeographic regions face similar threats of fragmentation. These include the Himalayas (Chakraborty et al. 2016; Mishra et al. 2020), Central India (Nayak et al. 2020), Northeast India (Talukdar et al. 2020), Rajasthan, India (Babbar et al. 2021), and the Western Ghats, India (Giriraj et al. 2010). Many envisage a multitude of adverse impacts from the loss of biodiversity to alterations in the regional climate, hydrological cycles, and the biophysical environment, ultimately affecting ecosystem services (Singh et al. 2015; Xu et al. 2009) and forest associations. Forest fragmentation results in the formation of small forest refugia or island landscapes that harbour stocks of native vegetation (Chakraborty et al. 2016). Many of these forest isolates are often surrounded by contrasting land uses such as agricultural fields or human settlements, which are also frequently bisected by linear infrastructural facilities such as roads, canals, railways, and powerlines (Marques et al. 2021; Nayak et al. 2020; Borda-de-Água et al. 2017; Desai and Bhargav 2010). As a consequence of these physical changes, the flow of wind, water, and nutrients across the landscapes, particularly in areas with topographical differences, is altered significantly (Watkins et al. 2003). The impact of these changes on energy fluxes will depend upon the duration of isolation and the degree of connectivity between the forest patches (Saunders et al. 1991). Although there appears to be no universally applicable minimum 'threshold' value of loss of native vegetation to assess the degree of threat (Fischer and Lindenmayer 2007), fragmentation in any magnitude exposes forests to further degradation. It is certain that fractionation increases the vulnerability of these patches to external disturbances.

Landscape metrics have been used to examine the extent of forest fragmentation and degradation (Reddy et al. 2013; Saikia et al. 2013). In recent years, open-source software tools such as FRAGSTATS are widely used to assess changes in forest structure as they are scientifically reliable, easy to use, and repeatable (Sharma et al. 2016; Midha and Mathur 2010). The present study aimed to (i) monitor the spatial and temporal changes in land use and land cover patterns in Mandla and Hoshangabad districts of Madhya Pradesh using LULC maps and (ii) characterize vegetation changes using landscape fragmentation matrices and the normalized deferential index, for the periods 2000 and 2017. The districts of Mandla and Hoshangabad were selected for the study as there is a dearth of information on these two districts where the land resources have been shaped by tribal communities. Although there are studies from other parts of India which have focused on aspects of deforestation and fragmentation (e.g. Singh et al. 2017b for Assam; Chavan et al. 2018 for Telangana), the focus in Central India has been on areas affected by mining (Areendran et al. 2013 for Singrauli).

13.2 Materials and Methods

13.2.1 Study Areas

Madhya Pradesh (M.P) is the second largest state in India (308,245 km^2) and also has the highest forest cover which is around 25.14% of its geographical area (Forest Survey of India 2019). The dominant vegetation type here is the tropical dry deciduous forest. Some of the economically important species in these forests which have a relatively ubiquitous distribution within the state are teak (*Tectona grandis*), saaj (*Terminalia elliptica*), tendu (*Diospyros melanoxylon*), dhawra (*Anogeissus latifolia*), mahua (*Madhuca longifolia*), amaltas (*Cassia fistul*a), bael (*Aegle marmelos*), and amla (*Emblica officinalis*). The study was carried out in the districts of Hoshangabad and Mandla.

Mandla lies between latitudes 22° 12′N and 23° 22″N and longitude 79° 59′23″ E and 81° 44′ 22″ E. It has a hilly terrain which is mostly under forest cover. The district is well known for Kanha National Park. About 57.23% of the population comprises tribal communities. The climate is tropical with moderate winters and severe summers. During the field visit, it was found that nearly all the rural households were dependent on forests to fulfil their everyday needs such as fuel-wood, fodder, and food. The majority of the farmers were small and marginal farmers with small landholdings (avg. landholding – 2.59 acres). Major forest products that were collected for self-consumption and sale were tendu (*D. melanoxylon*) leaves, mahua (*M. longifolia*) flowers and fruit, aonla (*E. officinalis*) fruit, achar (*B. lanzan*) kernels, and fuelwood. Many villagers were engaged in open livestock grazing in and around the forest. Hoshangabad lies between 22° 15′ N and 23° 00’N latitude and 77° 15′ E and 78° 42′E longitude and is situated at the southern bank of river Narmada. Although generally famous for its tourist attractions such as the Bhimbetka caves and Pachmarhi, it also supports the Satpura Tiger Reserve.

Characterized by a hot summer and dryness, the Hoshangabad district receives rainfall from the southwest monsoon. The map showing the geographic locations of the study districts is given in Fig. 13.1

District boundaries were extracted from planning maps obtained from the Survey of India office, Jabalpur, and National Atlas and Thematic Mapping Organisation (NATMO) office in Delhi. ESRI's ArcGIS (10.2.1), ERDAS Imagine software version 2014, FRAGSTATS 4.2, and Landscape fragmentation tool 2.0 were used for achieving the desired objectives. For LULC change detection satellite images of two time periods (2000 and 2017) were used. Details of the satellite images used are given in Table 13.1. All the images were downloaded from the United States

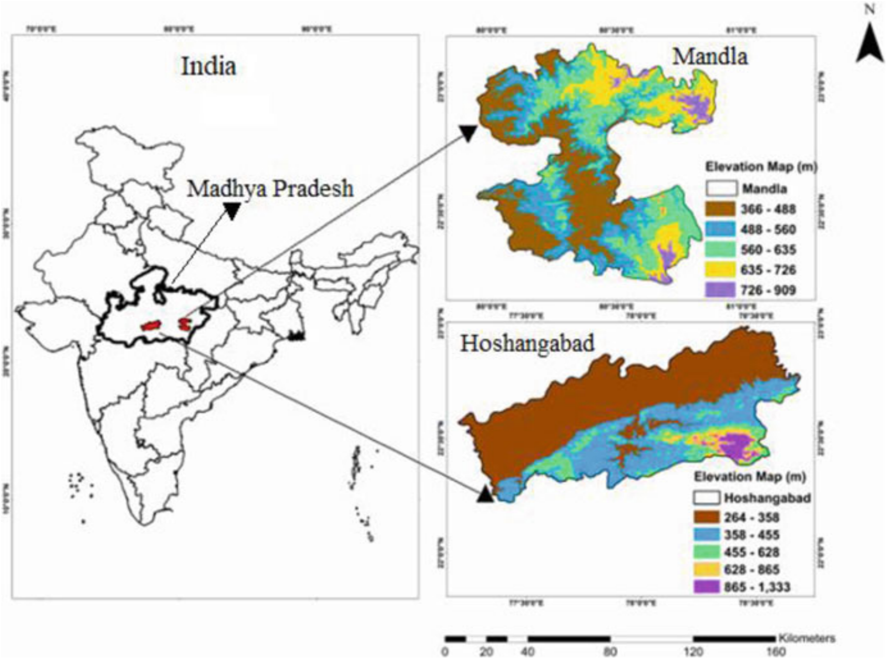

Fig. 13.1 Study area map. The locations of the two study districts within Madhya Pradesh (outlined). *Source:* (Prepared by the author)

Table 13.1 Details of the satellite data used

Satellite/time period	Sensor	Spatial resolution (m)	Bands used	Path/row	
				Mandla	Hoshangabad
Landsat 8 (Feb, March 2017)	Thermal infrared sensor	30	B1, B2, B3, B4, B5, B6, B7, B9	143/44 144/44 143/45	145/45 145/44
Landsat 7 ETM+ (Feb, March 2000)	Thematic Mapper	30	B1, B2, B3, B4, B5		

Geological Survey (USGS) earth explorer website. As given in Fig. 13.2 images were classified using unsupervised classification which was followed by recoding and cleaning. LULC maps were prepared to visualize the change using satellite imageries of the two time periods. Figure 13.2 gives the framework of the methodology followed for preparing the LULC maps. Different band layers from satellite data were stacked, mosaics were created, and the areas of interest were extracted from these images. Landsat satellites are a series of evolutionary satellites. Landsat 1–5 collects data in four different ranges or bands. Next in the series is Landsat 7, Landsat 6 being non-functional. Landsat 7 consists of eight bands. Landsat 8 has 11 bands but only bands 1–7 and band 9 were used in the present analysis. Band 8 is

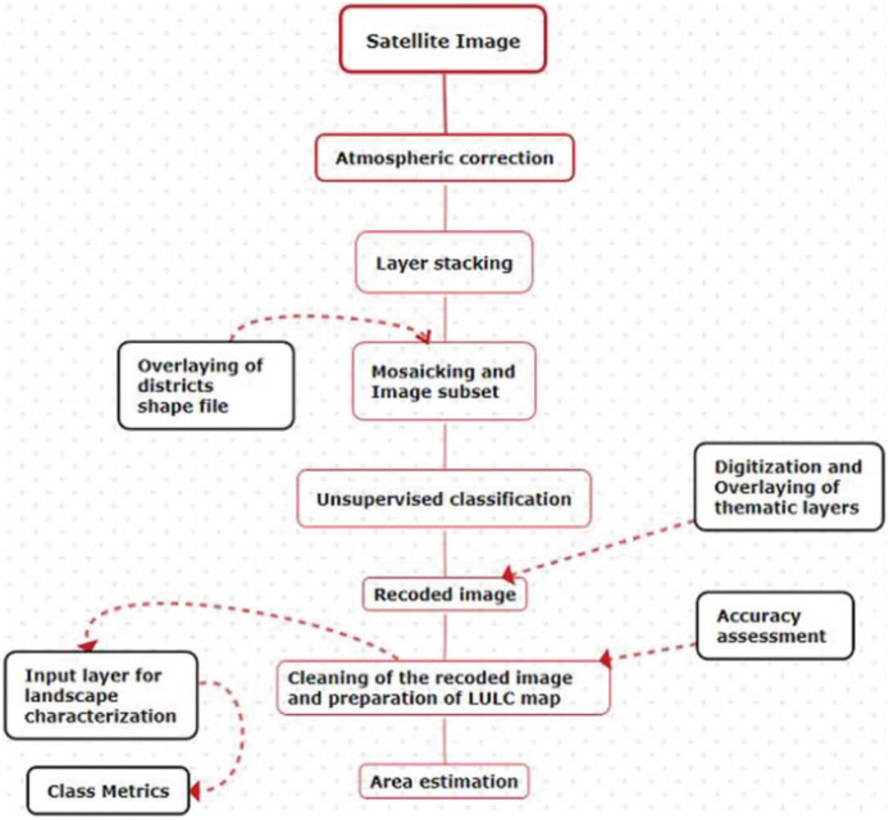

Fig. 13.2 Methodology followed for the LULC analysis

a panchromatic band and has a resolution of 15 m, while bands 10 and 11 have a resolution of 100 m. Since we need the same resolution bands for classification, we deliberately excluded bands 8, 10, and 11. Landsat 7 Enhanced Thematic Mapper has eight bands. From Landsat 7 bands 1, 2, 3, 4, and 5 were used for layer stacking. Mandla and Hoshangabad districts were masked from 2000 and 2017 satellite images. The study area was classified into eight classes following a series of steps that involved a hybrid approach for classifying the satellite data using digital image processing and visual analysis. The eight classes into which the areas of the two districts were categorized were dense forest, scrub forest, open forest, agricultural land, water bodies, fallow land, built-up areas, and open/sandy areas. Differentiation between dense and open forests was based on ground-truthing. Fallow land refers to the land that has been either abandoned after cultivation or is not under cultivation at the time of image capture. Open land refers to land that is not under any described land use, while sandy areas were primarily along the riverbeds that are not submerged. Water bodies include rivers, ponds, reservoirs, lakes, etc.

13.2.2 Accuracy Assessment

Post-classification accuracy assessment is an important step in LULC mapping. It compares the classified image with the actual features/relief on the ground. Ground truth points were collected from the forest ranges of Barella in Mandla and Sohagpur in Hoshangabad. In total, 297 points were used for accuracy assessment with a minimum of 30 points for each class. Results from accuracy assessment were reported as overall accuracy, producer's accuracy (omission errors), user's accuracy (commission errors), and the kappa statistic. Kappa statistics signify the classification precision, which expresses the level of agreement in a single value between pairwise comparisons of maps (Carletta 1996). It was Cohen (1960) who developed the kappa index for categorical data and it was initially used for psychology and psychiatric analysis. Later it was adopted for measuring the classification accuracy of remotely sensed data (Sousa et al. 2002). The strength of agreement varies from no agreement (−ve) to near perfect (0.81–1.00).

13.2.3 Landscape Characterization, Forest Fragmentation Indices, and NDMI

FRAGSTATS is a spatial pattern analysis program for categorical maps (McGarigal et al. 2012). Many scholars have used this tool to analyse the changes occurring to the landscape over time (Narmada et al. 2021; McGarigal et al. 2012; Mondal and Southworth 2010; Atesoglu and Tunay 2010; Giriraj et al. 2008). The landscape subject to analysis is user-defined and can represent any spatial phenomenon. FRAGSTATS assesses the areal extent and spatial ordering of patches throughout a landscape. Usually, three different types of metrics are calculated in FRAGSTATS: (a) Patch level – Patch metrics are defined for individual patches and characterize the spatial characteristic and context of patches and nature of patches, i.e. average patch size, number of patches, patch core area, etc. (b) Class level – Class metrics unify all the patches of a given type (class). Class indices individually quantify the configuration of each patch type in a particular class and give metrics as per the components of each class in the landscape. (c) Landscape level – Landscape configuration refers to the spatial characteristic and arrangement, position, or orientation of patches within the landscape or class (sum of all classes).

As our objective was to estimate the spatial characteristics of different classes, we derived six indices to quantify the class metrics. The six indices selected for analysis were total class area, number of patches, largest patch index, edge density, shape index, and total core area, details of which are given in Table 13.2. Figure 13.3 gives the interconnections between the total core area, largest patch index, edge density, and shape index. Shape complexity points to the geometry of patches, whether they are simple and closely packed or irregular and complex. Shape metrics reflect the overall shape complexity. The most common method to examine the complexity of

Table 13.2 Details of metrics used in landscape fragmentation analysis

Metrics	Unit	Formula	Description
Total class area	Hectare	The sum of the areas of all patches of the corresponding class type	It defines the extent of the landscape
Number of patches	None	Patch number in the class	Absolute numbers
Largest patch index	%	$a/A*100$ a = area of patch(m^2) A = total landscape area (m^2)	LPI approaches 0 when the largest patch in the landscape is increasingly small. LPI = 100 when the entire landscape consists of a single patch
Edge density	Meters/hectare	$(E/A)*10,000$ E = total length (m) of edge in landscape A = total landscape area (m^2)	It facilitates comparison among landscapes of varying sizes
Shape index	None	$(0.25*\ P)/\sqrt{a}$ p = perimeter of patch (m) a = area of patch(m^2) 0.25 = constant	SHAPE $\geq$1, without limit SHAPE = 1 when the patch is square and increases without limit as patch shape becomes more irregular
TCA	Hectare	Sum of the core areas of each patch of the corresponding class type	TCA approaches the total class area (CA) as the specified depth-of-edge distance(s) decreases and as patch shapes are simplified

Adopted from: Landscape Metrics for Categorical Map Patterns Tutorial by K. McGarigal

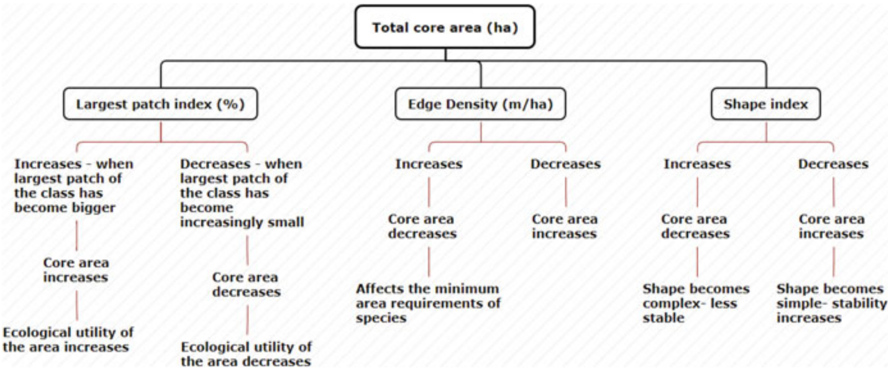

Fig. 13.3 Total core area as a function of the largest patch index, edge density, and shape index

the shape is to read the relative ratio of the perimeter (P) to the area (A). The interpretation varies among the various shape metrics, but in general, higher P/A values represent greater shape complexity or greater departure from simple Euclidean geometry (circular). The core area refers to the area of innermost patches when the buffer of the specified edge is eliminated, whereas the total core area is the sum of the core areas of each patch (m^2) of the corresponding class. The LULC classes were categorized based on a specified edge width of 100 m.

Simultaneously, vegetation health was assessed by examining the moisture content of vegetation using the Normalized Difference Moisture Index (NDMI). Though the normalized differential vegetation index (NDVI) is the most commonly used index for studies on vegetation cover, some have reported that NDMI is more useful for assessing forest health (Dutta et al. 2021; Zhang et al. 2016; Wang et al. 2010; Goodwin et al. 2008). NDMI has a strongly negative but linear correlation with Land Surface Temperature (LST), while the same is not true for LST and NDVI (weak correlation) (Li et al. 2017). As a result, NMDI helps in assessing moisture stress on vegetation better, a natural precursor to forest health, than does the NDVI. The calculation of the NDVI values was based on the following formula:

$$\mathrm{NDMI} = \frac{\mathrm{NIR} - \mathrm{SWIR}}{\mathrm{NIR} + \mathrm{SWIR}}$$

where NIR is near infrared and SWIR is shortwave infrared.

The selection of bands varies with the choice of Landsat image. For Landsat 8 bands 5 and 6 were used, while for Landsat 7 bands 4 and 5 were used. NDMI values range between −1 and + 1. Though the NDMI values can also vary according to the phenological stages of the stand, positive values are interpreted as the presence of healthy biomass with high moisture content, whereas areas where NDMI values are low indicate that vegetation is under water stress (Dutta et al. 2021).

13.3 Results

13.3.1 Classification Accuracy

The classification accuracy was evaluated through cross-referencing the features with the imagery available on Google Earth (https://earth.google.com/) (Sharma et al. 2016). During the field survey, it was found that at some place's barren/uncultivated rocky lands situated between the boundary of forest and agricultural fields around forest villages were misclassified as agricultural lands. Within the forest, at a few places, water bodies and vegetation spectral signatures were found to be confusing. The lower accuracy values observed in the classes agricultural land, fallow/barren land, and water bodies at a few locations are due to their similar reflectance values. It was found that at some places under dense canopies, the signature of broad leaves and their shadows mimicked water and so were misinterpreted. Acharya et al. (2018) also attributed lower accuracy of water bodies because of the noise from shadows, clouds, and overhead canopies within forests. However, the overall accuracy reported here is within acceptable limits (80–99%) (Babbar et al. 2021; Mishra et al. 2020; Singh et al. 2017a; Chakraborty et al. 2016; Jain et al. 2016; Ellis et al. 2010; Anderson et al. 1976). The overall accuracies for Mandla for 2000 and 2017 were 84.18% (kappa 0.82) and 87.21% (kappa 0.85), respectively. At Hoshangabad, the observed overall accuracy was 83.39% (kappa

Table 13.3 Producer's and user's accuracy assessment for Mandla and Hoshangabad (2000 and 2017)

	Mandla				Hoshangabad			
LULC class	2000		2017		2000		2017	
	PA	UA	PA	UA	PA	UA	PA	UA
Dense forest	90.24	80.43	85.71	92.31	83.78	81.58	86.84	80.49
Open forest	90.32	80.00	84.21	94.12	83.33	81.08	81.58	88.57
Agricultural land	82.22	88.10	84.44	82.61	82.93	79.07	86.36	82.61
Water body	86.67	81.25	86.21	86.21	86.11	77.50	78.38	80.56
Fallow/barren land	71.11	94.12	83.33	93.75	76.32	93.55	76.47	89.66
Built-up	90.32	87.50	100.00	89.47	83.78	91.18	94.12	94.12
Scrub forest	87.18	87.18	90.24	82.22	84.62	86.84	84.62	82.50
Open land/sand	80.00	75.68	84.38	79.41	87.10	79.41	87.88	80.56
Overall accuracy (%)	84.18		87.21		83.39		84.51	
Kappa coefficient	0.82		0.85		0.81		0.82	

PA-Producers accuracy, UA- User's accuracy

0.81) for 2000 and 84.51% (kappa 0.82) for 2017. Table 13.3 gives the class-wise producer's and user's accuracy for Mandla and Hoshangabad for the two considered time periods (2000 and 2017).

13.3.2 Temporal Changes in LULC

The analysis shows that the dense forest cover increased in both districts. An increase in the core area of forests in Kanha National Park in the Mandla district has also been reported by Devi et al. (2017). But the same is not true for open forests, as during the study period Mandla and Hoshangabad have lost 8.73% and 6.43% of these forests, respectively. Overall, there has been a cumulative loss of forest cover in both districts. In Mandla, the total forest cover (dense + open) has decreased from 2432 to 2155 km^2 (net loss of 4.66%), while at Hoshangabad the total forest cover has decreased from 2254 to 1976 km^2 (net loss of 4.13%) between 2000 and 2017. We also found that Mandla has lost over 18% of its scrub forest, while its net area under agriculture has increased by 11%. Forests form the major land cover at Mandla, while agriculture is the second major land use class. In Hoshangabad the areas under agriculture and scrub forests have increased by 3.57% and 1.18%. Since agriculture is the major land use in Hoshangabad (44.69% in 2000), the change observed is less evident here (48.26%). At Hoshangabad open lands have decreased by 2.52%. There is also a marginal increase in the water bodies in both districts (0.99% in Mandla and 0.56% in Hoshangabad). Figure 13.4 gives the net change in LULC (%), while Fig. 13.5 gives the maps for 2000 and 2017 in both the study districts. Table 13.4 gives the class-wise land distribution (in km^2) in the Mandla and Hoshangabad districts.

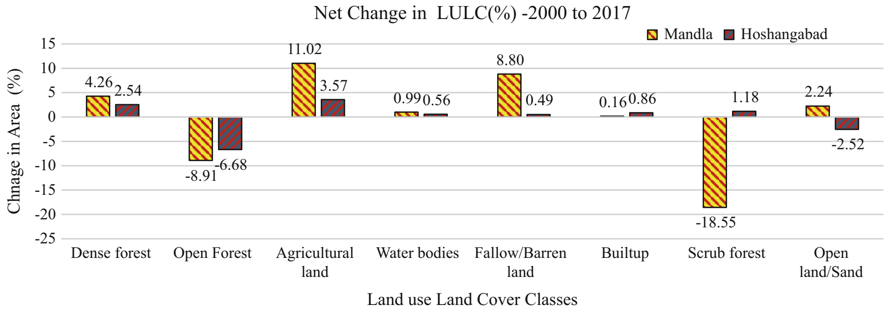

Fig. 13.4 Net changes (%) in LULC types observed between 2000 and 2017

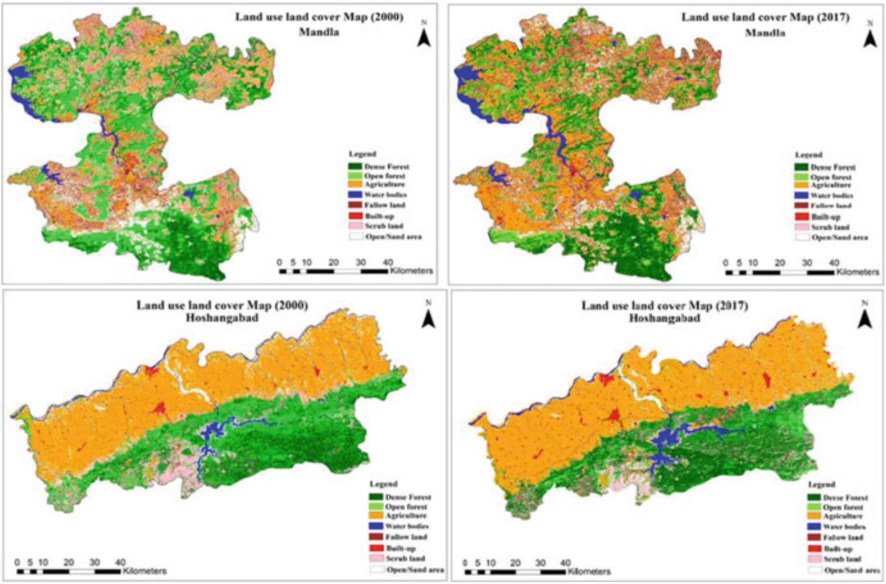

Fig. 13.5 LULC changes in the districts of Mandla and Hoshangabad

13.3.3 Landscape Characterization and Forest Fragmentation

13.3.3.1 Mandla

LULC maps have conveyed that the area falling within the class 'dense forest' increased in 2017 at Mandla but the number of patches (NP) decreased. It was, however, noted that the reduction in the number of patches is primarily due to the consolidation of patches and not owing to conversion to other land uses. This was evident from the largest patch index (LPI) value for 'dense forests' which increased

Table 13.4 Class-wise land distribution in Mandla and Hoshangabad districts

	Mandla					Hoshangabad				
	2000		2017			2000		2017		
LULC classes	Area (km^2)	Area (%)	Area (km^2)	Area (%)	Net change	Area (km^2)	Area (%)	Area (km^2)	Area (%)	Net change
Dense forest	1022.66	17.17	1276.28	21.43	4.26	1255.48	18.66	1426.4	21.20	2.54
Open forest	1409.8	23.67	878.89	14.76	−8.91	999.11	14.85	549.8	8.17	−6.68
Agricultural land	1093.66	18.36	1750.05	29.39	11.02	3006.32	44.69	3246.16	48.26	3.57
Water bodies	168.71	2.83	227.67	3.82	0.99	181.72	2.70	219.44	3.26	0.56
Fallow/barren land	383.21	6.43	907.1	15.23	8.80	38.2	0.57	71.38	1.06	0.49
Built-up	43.9	0.74	53.661	0.90	0.16	103.88	1.54	161.61	2.40	0.86
Scrub forest	1454.62	24.42	349.61	5.87	−18.55	585.97	8.71	665.47	9.89	1.18
Open land/sand	379.04	6.36	512.32	8.60	2.24	556.18	8.27	386.59	5.75	−2.52
Total	5955.60	100	5955.58	100		6726.86	100	6726.85	100	

from 2.74% to 4.23%. The core area of dense forest patches increased over 17 years (2000 to 2017) by 27524.24 ha in Mandla, which is consistent with the observations documented in the State of Forest Report (2017) for Madhya Pradesh. As edge density is a measure of spatial heterogeneity and class compactness, it should be read in relation to the total area and number of forest patches under the class. For the class ‘dense forests’ the edge density decreased from 39.58 m/ha in 2000 to 33.99 m/ha in 2017. This could be due to the amalgamation of the number of differently sized patches. If the edge density values increased along with an increase in the total forest area, this could be interpreted as an increase in forest edges, hence more fragmented patches. The shape index (SI) is the measure of the shape complexity based on the perimeter of the patches. The higher the SI, the greater the shape complexity and thus the more the vulnerability to edge effects. The ‘dense forests’ has not shown much change with respect to the shape index values (1.30 in 2000 to 1.34 in 2017). The areas under the classes ‘open forest’ and ‘scrub forest’ have decreased from 140980.14 ha (2000) to 890262.05 ha (2017) and from 145462.05 ha (2000) to 22767.39 ha (2017), respectively. The edge density of scrub forests has reduced to about 6% (3.96 m/ha) from what it was in 2000 (65.96 m/ha). Though a lower edge density is an indication of the expansion of core areas, it is not the case here. In the present case, the reduction in the edge density is due to the removal of scrub forest patches, which is suggested from the reduction in the total core area and the reduced size of the largest patch of scrub forests. In the ‘open forest’ class the area of the largest patch also declined by 0.53%. The scrub forests have not shown a major change in the shape index values (1.40 in 2000 to 1.39 in 2017), whereas for open forests it increased from 1.35 to 1.42, which suggests that patches have become more irregular and discontinuous and hence would be more vulnerable to edge effects. The total core area for both the scrub and open forests has decreased by 22,639.32 ha and 1787.71 ha between 2000 and 2017, respectively.

The area under agriculture increased by 50,707.35 ha. As in the case of dense forests, the number of patches under the class ‘agriculture’ decreased but the largest patch size increased from 0.38% to 2.51%. Similarly, the total core area under agriculture also increased from 16827.30 ha to 46866.78 ha. The change in the shape index was not significant (1.30 to 1.34). An increase in edge density and area together with a non-significant change in the shape index suggests an expansion of the agricultural fields into new areas.

Built-up areas have increased by 48,194.82 ha, while the number of patches also increased from 1985 in 2000 to 38,968 patches in 2017. With respect to the largest forest patch size and the total core area for built-up areas, these are similar to trends observed in agricultural lands. An increased area and a greater number of patches have contributed to an increased edge density (20.15 m/ha) of built-up areas in 2017. The change in the shape index values (1.38 to 1.24) indicates that the patches that were previously small (in 2000) and widely spread have become more continuous and consolidated, owing to the expansion of built-up areas. The largest loss occurred with respect to open lands/sandy areas (dry river beds) – the extent decreased by

32,539.32 ha, while the core area decreased significantly from 10488.51 ha in 2000 to 1454.67 ha in 2017. There was a significant decrease in the area of the largest patch size (0.25 to 0.04), whereas the number of patches also decreased from 34,313 in 2000 to a mere 1559 in 2017. With the decline in area, the edge density also reduced to 1.52 m/ha, a meagre 9% of what it was in 2000 (15.62 m/ha). Open forest patches and dry river beds are under constant threat from encroachment and conversion to other preferred land uses. Table 13.5 gives the details of landscape characterization at Mandla.

13.3.3.2 Hoshangabad

At Hoshangabad the area under the class ‘dense forest’ increased by 17091.81 ha between 2000 and 2017. The largest patch size values of dense forests have undergone a sharp decline – from 10.11 ha in 2000 to 6.62 ha in 2017. An increase in the number of forest patches along with an increase in the total core area indicates the creation of new forest patches. For open forests, the total area decreased by 44931.43 ha, whereas scrub forests increased by 7950.53 ha between 2000 and 2017. Similar declines were noted for scrub and open forests from 2000 to 2017 [largest patch size – open forest, 1.38 (2000) to 0.36 (2017); scrub forests, 1.77 (2000) to 0.88 (2017)]. Open forests have become severely fragmented leading to a large number of small patches evident from lower edge density (26.64) and shape complexity index (1.25) values. The total core area under open forests was also reduced by 6275.88 ha between 2000 and 2017. However, scrub forests increased by 7950.51 ha in the same period although they appear to be disintegrated (as the number of patches increased by 24,029). This change is detrimental as the total core area has drastically reduced the area of the largest patch of scrub forests in 2017 which was half that observed in 2000. This indicates that, though the total area under this class has increased along with the number of patches, they are isolated in nature and are of a smaller size. The whole area is within the specified edge depth of 100 m from the perimeter of the patch and fails to contribute to the core area. Smaller-sized patches are less complex and would be vulnerable to greater edge effects and encroachments. The area under agriculture has increased, although the number of patches has reduced. The total core area under agriculture increased by 13691.25 ha between 2000 and 2017. The largest patch area too increased, indicating an expansion of cultivated areas. The built-up areas have increased, the number of patches reduced, and the total core area increased during the period of observation. The area of the largest patch also increased, indicating an expansion of settlements and other establishments. The area of open lands and sandy areas (dry river beds) decreased, whereas the number of patches increased. Table 13.6 gives the landscape characterization at Hoshangabad.

Table 13.5 Landscape characterization in the Mandla district (2000 and 2017)

Fragmentation indices	Dense forest		Open forest		Scrub land		Agricultural land		Built-up		Open land	
	2000	2017	2000	2017	2000	2017	2000	2017	2000	2017	2000	2017
Class area (ha)	102262.6	127919.2	140980.1	89026.3	145462.1	22767.4	109365.6	160072.9	4390.38	52585.2	37,905	5365.71
Number of patches	58,306	30,113	67,887	48,964	66,117	1952	90,929	65,181	1985	38,968	34,313	1559
LPI (%)	2.74	4.23	1.18	0.65	0.5	0.35	0.38	2.51	0.02	0.19	0.25	0.04
Edge density (m/ha)	39.58	33.99	45.09	58.29	65.96	3.96	58.68	53.46	1.5	20.15	15.62	1.52
Shape index	1.3	1.34	1.35	1.42	1.4	1.39	1.3	1.34	1.38	1.24	1.23	1.4
Total core area (ha)	26172.9	53797.14	31771.08	9131.76	16748.01	14960.3	16827.3	46866.78	952.65	12198.1	10488.5	1454.67

Table 13.6 Landscape characterization in the Hoshangabad district (2000 and 2017)

Fragmentation indices	Dense forest		Open forest		Scrub land		Agricultural land		Built-up		Open land	
	2000	2017	2000	2017	2000	2017	2000	2017	2000	2017	2000	2017
Class area (ha)	125547.8	142639.6	99911.43	54,980	58596.57	66547.1	300,632	324616.4	10387.7	16160.9	55568.8	38659.2
Number of patches	26,316	47,298	49,618	79,490	46,646	70,675	11,594	6881	6444	3798	69,036	86,765
Largest patch index (%)	10.11	6.62	1.38	0.36	1.77	0.88	12.11	12.18	0.17	0.32	0.62	0.25
Edge density (m/ha)	71.87	33.41	73.94	26.64	38.74	27.34	23.26	44.59	5.81	4.66	45.58	19.53
Shape index	1.31	1.25	1.36	1.25	1.27	1.24	1.21	1.27	1.27	1.33	1.25	1.18
Total core area (ha)	33799.77	46372.77	10385.28	4109.4	15525.54	7446.06	221,872	235563.2	2840	8071.56	10593.5	6603.39

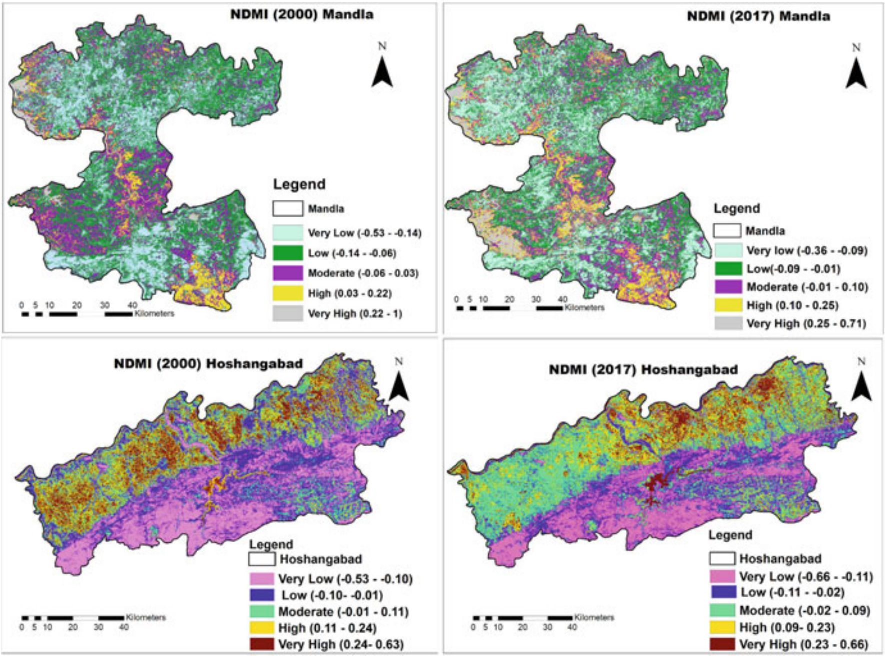

Fig. 13.6 Normalized Difference Moisture Index (NDMI) for Mandla and Hoshangabad for the years 2000 and 2107

13.3.4 Normalised Differential Moisture Index

To assess the health status of vegetation based on the level of moisture, the NDMI values were divided into five categories – very low, low, moderate, high, and very high (Fig. 13.6). The range of values under each category varied year-wise and district-wise. At Mandla these values were very low (−0.53–0.14 in 2000 and −0.36–0.09 in 2017), low (−0.14–0.06 in 2000 and −0.09–-0.01 in 2017), moderate (−0.06–0.03 in 2000 and − 0.01–0.10 in 2017), high (0.03–0.22 in 2000 and 0.10–0.25 in 2017), and very high (0.22–1 in 2000 and 0.25–0.71 in 2017), whereas in Hoshangabad the values were very low (−0.53–0.10 in 2000 and −0.66–0.11 in 2017), low (− 0.10–0.01 in 2000 and − 0.11–0.02 in 2017), moderate (−0.01–0.11 in 2000 and − 0.02–0.09 in 2017), high (0.11–0.24 in 2000 and 0.09–0.23 in 2017), and very high (0.24–0.63 in 2000 and 0.23–0.66 in 2019). It is evident from the NDMI values that the biomass and moisture content is higher in forests of Mandla (1 and 0.71 in 2000 and 2017, respectively) than in Hoshangabad. In Mandla, the areas with low moisture and biomass content have transitioned to very low moisture levels in 2017 in the central part (poor quality forests), although in the southern part of the district the moisture content has increased (healthy forests) At Hoshangabad, high NDMI values were observed across the northern part of the district which is under cultivation, although a major part of forest vegetation was seen to be under moisture stress. In comparison, the forests in the south-western part show a relatively better moisture index.

13.4 Discussion

The increase in the overall forest cover of Madhya Pradesh is credited to an increase in the area under forest plantations (ISFR, 2019) and better management practices. The present study focused on two districts in Madhya Pradesh, Mandla and Hoshangabad. The Mandla district supports a large tribal community, around 57% of the inhabitants (www.censusindia.com); hence, forest-related employment and agriculture (farming) are the main livelihood practices here and no major industrial developments have occurred in this district. In Hoshangabad, the prevalence of a good irrigation network and the availability of large extents of fertile alluvial plains have resulted in agriculture being the most practiced occupation in the district, which was evident from the higher NDMI values in the upper areas.

The present study revealed that in both districts, the loss of forest areas due to the expansion in agriculture or in the built-up areas has been marginal (less than 1%), although there was a considerable loss in open forest areas. Our results are in line with Sharma et al. (2016) who report an increase in dense forest cover but a decrease in open forest cover. On the contrary, Ramachandra et al. (2016) studied forest fragmentation in Central Western Ghats, India, and found that forest cover declined, and this was attributed to unplanned developmental projects or conversion to other non-forest categories such as croplands and plantations. They also noted that changes in landscape structure occurred due to locally relevant socio-economic variables. Similarly, Keles et al. (2008) reported a decrease in the average forest patch sizes due to human interventions, resulting in irregular land cover types. Expansion of agriculture and settlements is occurring at the cost of ecologically important land cover types such as scrub forests, open areas, and dry river beds (Brander 1994). Our study also reports decreases in the extent of open forests, scrub forests, and open lands, whereas the area under the classis's 'agriculture' and 'built up' increased. With the expansion of human population, there is an invariable increase in forest-based industries and illegal encroachments for agriculture, which exerts pressure on forest resources (FAO 2016). Anthropogenic activities (e.g. development, timber harvesting) can disrupt the structural integrity of landscapes and most often impede ecological processes (e.g. movement of organisms) (Gardner et al. 1993).

The increase in the dense forest cover is the result of consistent efforts by the management and concerned authorities in the past, which is also reflected by a relatively higher moisture/vegetation index in some parts of the districts. The Forest Survey of India (2015) attributed the increase in forest cover in the state of Madhya Pradesh to increased plantation activities within the forest, this being a cause for concern as it creates patchiness of the forest (Estreguil et al. 2013; Almoussawi et al.

2019). It must be noted that (i) the increase in dense forest cover is not uniform and is limited to sections of the forest as evident from NDMI values and (ii) the establishment of plantations of timber species on a large scale in the Mandla district in the past has significantly altered the present-day species composition in the forest. For instance, in 1930 *Tectona grandis* (teak) occupied only 39% of the forest in West Mandla but the increase in market demand for timber induced forest departments to reorient their management policies, which resulted in a larger amount of forest land being compromised for plantations. *T. grandis* in recent years covers around 82.5% of the forest area (as per forest working plan, West Mandla 2006–2007 to 2015–2016). This also results in the loss of vegetation heterogeneity in the forest. Monoculture plantations, although they can result in an increase in tree cover, will not be beneficial in the long run. For example, the remaining forests (17.5%) which comprise mixed species are expected to support the needs of the local communities for forest products and the requirements of livestock and wildlife. The interspersed monoculture stands disrupt connectivity between synchronized stages of succession in natural forests and create contrasts along the edges of the patches. While studying the impact of tree diversity on productivity, Mahaut et al. (2019) observed strong and positive effects from increased diversity of vegetation on both above-ground and below-ground biomass production (Richards et al. 2010). They also observed that each species under investigation did not contribute equally to the functions of the ecosystem, and hence, through the conversion of a heterogeneous forest to a homogenous monoculture plantation, we forego the benefits of some species. A forest with a high diversity of tree species provides suitable conditions for ecological niches to develop and strengthens the existing species interactions while simultaneously facilitating the evolution of new species associations (Liu et al. 2018).

It has become clear from numerous studies that the many impacts of forest fragmentation are interconnected (Saiter et al. 2011; Paula et al. 2015; Arruda and Eisenlohr 2016; Duarte et al. 2019; Pereira et al. 2021; Santos et al. 2021). Forest fragmentation, driven by multiple factors, is recognized as one of the major causes of biodiversity loss (Tilman 2004) and altered ecosystem functioning across biomes. Pereira et al. (2021) studied the footprints of forest fragmentation by examining the impacts of edge effects on successional dynamics in Brazilian forests and report high mortality of trees in forest fragments surrounded by pasturelands. Here high seedling recruitment and equally high mortality were attributed to adverse consequences of fragmentation. Increased light intensity along edges combined with low humidity conditions favours the rapid growth of pioneer species. Almoussawi et al. (2019) explored how forest species (specialist vs generalist) responded to fragmentation and reported on their negative impacts on the interior-sensitive specialists, while the generalist's benefit. Herbaceous vegetation may cause competitive exclusion of forest specialists who are poor in resource exploitation and are not adapted to unstable microclimatic conditions of forest edges. On the other hand, it has been found that agricultural practices along the forest boundaries create favourable conditions for generalists (Fischer and Lindenmayer 2007). Thus, fragmentation leads to structural and floristic changes in characteristics of the plant communities of the forest edges and interior.

Forest edges also act as tangible barriers to the dispersal of forest specialists between neighbouring forests. This increases the tendency of specialist species, the slow colonizers, to concentrate in small areas, whereas the fast colonizers, the generalist species, increase their area of coverage. The abundance of forest generalists tends to decline from the edges to the forest interior, and specialists vice versa. These reverse patterns of abundance shown by specialists and generalists are a result of niche partitioning along the gradients of light, moisture, and soil conditions across edges and core areas of the forest. The depths up to which edge effects can have their influence are not uniform across ecosystems. It has been shown to be between 20 and 50 m (Hérault and Honnay 2005) and between 100 and 200 m for the forest interior (Hardiman et al. 2013). Edge effects are more deleterious for smaller and isolated habitat patches. Animals are similarly affected by fragmentation. Shahabuddin et al. (2021) assessed the effects of land use change on forest bird species in the Himalayas and reported that it negatively affected species richness and species composition. Here too it has been noted that birds that are forest specialists are highly vulnerable to land use change. Forest specialists often use mosaics of tree species found in natural forests. Therefore, the conversion of natural forests to other land use types forces these species to alter their feeding and nesting behaviour, which may lead to the local extinction of some species. Santos et al. (2021) assessing bird communities in Brazilian forests show that the abundance of birds was greater at the centre of the forest than at the edges. They further state that species occupying the forest edges demonstrated a behavioural shift which was required for communicating at the noisy forest edges. They observed that species were deploying compensatory mechanisms to adjust their acoustic conduct which is identified as the Lombard effect (Garnier and Henrich 2014). Species were investing more energy to increase their amplitude, call frequency, and call duration (Pieretti et al. 2015; Duarte et al. 2019). Pollinators are also negatively affected by land use conversions (Shahabuddin et al. 2021). As the natural areas become increasingly isolated, the links between the individual segments reduce. As forests become smaller and more distant from one another, their carrying capacity and the potential to provide ecological services also decline (Brander 1994). This alters the relationship between alpha and beta diversity with respect to both flora and fauna (Khurana and Singh 2001; Starzomski et al. 2008; Belote et al. 2009; Almoussawi et al. 2019). It must therefore be highlighted that maintaining original forest habitats should be considered a top priority.

13.5 Conclusion

This study assessed the changes in LULC patterns in two districts of Madhya Pradesh using Landsat data for two time periods – 2000 and 2017. The results reveal that forest cover is the major land cover type in Mandla, while agriculture is the major land use type in Hoshangabad. As a result of an afforestation drive by the Forest Department, the dense forest area has increased at both the study sites, which is reflected by the higher moisture index values. However, it was found that there is a net loss of forest area in both districts, as the loss of area under open forests is greater than the area gained with respect to the dense forests. Replacement of mixed species forests at Mandla with homogenous *T. grandis* stands is a matter of concern, as such monocultures do not contribute to the resilience of the forest. To reap the benefits of multispecies ecosystems and to reduce pressures on existing forest resources, conscious efforts are needed to reverse this change. The trends in the number of patches and the extent of the largest patch suggest that forest fringes that are adjacent to agricultural lands are more likely to undergo land diversion in both districts. The expansion of built-up areas is not significant in the two studied districts. However, the shape index values indicate that built-up areas are on the rise and have become more consolidated due to expansion. Results also show an increase in the total core areas with respect to agriculture. This may suggest the lack of other employment opportunities, a matter that has to be resolved particularly as it relates to tribal communities in the two districts under consideration. New employment opportunities must be in line with their way of living and must have a minimal impact on the forests on which they depend.

This study also accentuates the ability of geospatial techniques in documenting the changing dynamics in landscapes in terms of LULC. As Peter Drucker said, 'you can't manage what you can't measure', this study while addressing an information gap in the two districts Mandla and Hoshangabad provides an information base upon which policy decisions could be made to ensure sustainability in land use planning in the tiger capital of India.

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Chapter 14
Analyzing the Trend, Pattern, and Hotspots of Forest Fires Using Geospatial Techniques: A Case Study of Almora District, India

Shuaib Ahemed, Sk Mithun, Mary Tahir, and Haseena Hashia

Abstract Forest fire hotspot analysis is a widely applied tool for estimating biodiversity, wildlife, people, and property in danger. The present study aims to analyze the trend and pattern of forest fires and identify the forest fire hotspot region with the help of geospatial techniques in Almora district of Uttarakhand. The fire point data collected from the Forest Survey of India (FSI) was used to analyze the trends of forest fires annually, monthly, and day-wise. Kernel density was used to analyze shifting patterns of forest fires and identify the forest fire hotspot with the help of Getis-Ord Gi* Method. The results reveal that the density of fire occurrences has increased considerably during the study period. During 2001–2018, a sum of 7380 fire incidents was recorded over 3150 sq.km. Moreover, most of the fires occurred in 2012 and 2016. Approximately 43% of the forest fires occurred in April and June, and about 41% of incidents occurred in May. However, the highest and lowest intensity of fire occurrences were found in the Takula block and Syaldey block of the district, respectively. These findings provide a systematic approach to understand forest fire patterns in light of historical forest fire incidents. This research emphasizes support and encourages more studies on forest fire assessment for monitoring and prevention policies and offers a preliminary especially explicit model of fire occurrence expectations in Almora district.

Keywords Forest fire · Kernel density · Getis-Ord Gi* hotspot · Almora district · Remote sensing and GIS · Environmental monitoring · Sustainability

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14.1 Introduction

Fire is one of the highly impacted forces on Earth. It plays an important role in the evolution of biomes and the dynamics of the Earth's climate. During the late Silurian Period (around 420 million years ago), the oldest fire signature on Earth has been identified from charcoal in the rocks. Though greenery had spread on the earth's surface at that point, the first extensive wildfires have been recorded on the basis of the geological history of the earth during the early Carboniferous Period (around 345 million years ago) (Bond 2019). Forests are known to be a stabilizing component of climate. They regulate ecosystems in a systematic way, drive an integral part in the carbon cycle, protect biodiversity, support livelihoods, and supply goods and services that activate the process of sustainable growth on earth (Schulman 2015). Forest fire is a major hazard for the world's forests.

Every year, fire destroys millions of hectares of forest around the world and creates a lot of problems in all dynamic aspects of human life through economic, environmental, and social disturbances (Satendra and Kaushik 2014). Out of the total globally occurring forest fires, approximately 4% of forest fires have natural causes which are related to extreme weather conditions such as high temperatures, drought and storms, and lightning. On other hand, human causes are responsible for forest fires such as the burning of debris, equipment use, and malfunctions, careless tourism, shifting cultivation, and intentional acts of arson. At the global level, the effects of forest fires are severe on species diversity, which covers 84% of the earth's surface of all eco-regions. This situation has been resulted by changing fire intensities and frequencies. On the other side, the remaining 16% of events of occurring fires are ecologically adjustable. Fire-sensitive ecosystems are under the more threatening situations with 93% of their surface being risky.

Environmental scientists and researchers have investigated various elements of forest fires, including causes of forest fires and its impact on the environment, society, economy, management, and its zonation, mapping, and other aspects with the application of remote sensing and GIS (Pourghasemi 2015; Wulder and Franklin 2006). Numerous studies have been conducted on forest fires, demonstrating the use of remote sensing and the utility of mapping (Adab et al. 2013; Chuvieco and Congalton 1989; Pourghasemi 2015; Prosper-Laget et al. 1998; Wulder and Franklin 2006). There are many aspects regarding the trends and pattern of forest fires with the help of remote sensing (Dwyer et al. 2000; Riaño et al. 2003). Ullah et al. (2013) investigated the distribution of forest fires in the context of spatiotemporal change and the estimation of fire weather indexes in China from 2000 to 2009. The kernel density approach was used to map hotspots and forest fire risk zones in the Yeguare Region of Southeastern Honduras (Cáceres 2011). Koutsias et al. (2014) used kernel density that had a vital role in fire risk modeling was also utilized to construct forest risk zone. The different buffer control points of kernel density were used, and due weightage of kernel density was provided to prepare the forest risk zone map at the national level in Greece. A different model of forest fire risk was used by Stralberg et al. (2018) for increasing the frequency of extreme fire weather in Canada with climate change. Gralewicz et al. (2012) also studied to quantify the spatial and temporal patterns of wildfire in Canada. Recently, Sahana and Ganaie (2017) used frequency ratio model to assess landscape vulnerability to forest fire in Rudraprayag district, Uttarakhand, India. Further, Sahana et al. (2018) linked forest fire to the deforestation susceptibility.

Forest fires are a significant threat to the existence of forests in Almora district. The present study aims to analyze the occurrences of forest fires from 2000 to 2018 in Almora district of Uttarakhand State of India and identify the hotspots of forest fires within the district. The analyses of the datasets reveal that approximately 68% of forest fires occur in May and June. Earlier researches such as Stralberg et al. (2018), Gralewicz et al. (2012), Dwyer et al. (2000), and Riaño et al. (2003) attempted to examine forest fires happening in various aspects of their trends and patterns of forest fire. This study is essential for identifying the background of forest fire risk and affected region in the form of a hotspot of forest fire in the study area. In Almora district, forest fires pose the greatest threat, responsible for the loss of life and property and creating great havoc. This study attempts to assess forest fires in the context of the trends, patterns, and hotspots of forest fires by using occurrences of forest fires. The use of kernel density without grid impact and Getis-Ord Gi* method of the hotspot analysis to identify forest fire locations represents the research gap. The Getis-Ord Gi* hotspot method provides strong evidence for identifying forest fire hotspots throughout the study period.

14.2 Study Area

The district of Almora, located in the Kumaon division of Uttarakhand state in India, is the research area in the present study (Fig. 14.1). The district of Almora is a part of Kumaon Himalaya, bordered by Champawat and Pithoragarh in the east; by Bageshwar, Chamoli, and Rudraprayag in the north; by Pauri in the west; and by Nainital in the south. The district extends over an area of 3134 sq.km. The administrative setup comprises 11 community development blocks. The agricultural activity is of subsistence in nature, primarily practiced in river terraces, intermountain valleys, and gentle hilly slopes. According to the Census in India (2011), Almora district had a population of 621,927 and ranked 517th district in India in terms of population. The population density in Almora district is 198 people/sq. km, with 1142 females for every 1000 men, an 81.06% literacy rate, and a population growth rate of −1.73% between 2001 and 2011.

Uttarakhand has a history of having a high frequency of forest fires. As a Himalayan state, it is rich in natural resources and has constituted a notable eco-region. With reference to the Champion and Seth Classification (1968), the forest area of Uttarakhand state is categorized into 9 forest type groups, which are

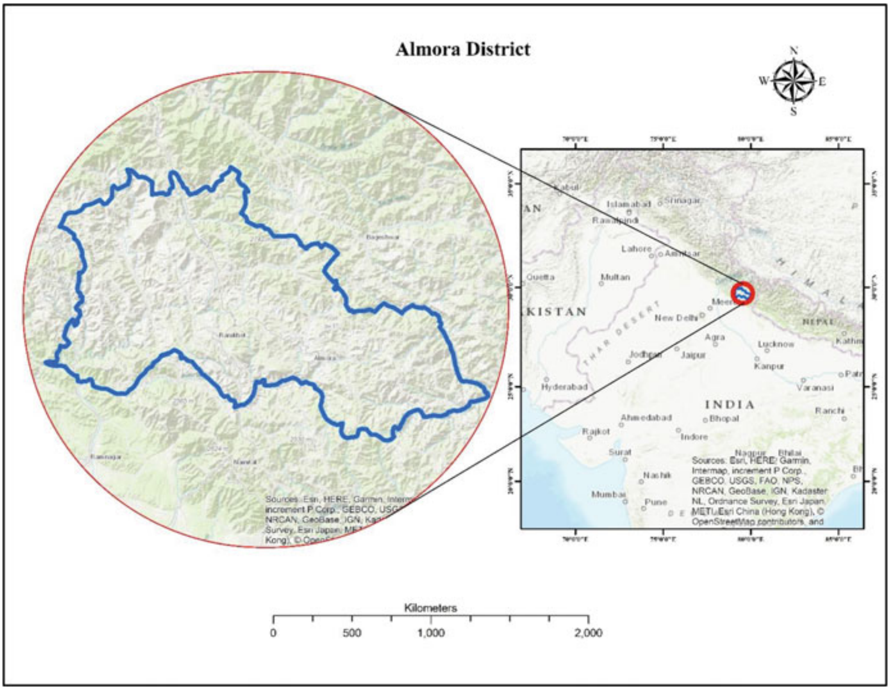

Fig. 14.1 Location map of Almora district

further subdivided into 43 forest types. The forest cover area of Uttarakhand state has been measured at 38,000 sq.km, accounting for 71.05% of the geographical area. It has the most forest cover among India's northern states.

These woodland areas are extremely vulnerable to forest fires (Pokhriyal et al., 2020). The occurrence of forest fires has been a regular event in this region, and it has become more active in the last two decades (Tripathi et al., 2021). In Uttarakhand state, forest fire has been categorized into three categories: the first category is ground fires, the second category shows surface fires, and the last category denotes crown fires. This fire is dependent upon organic material that is founded on land surface. It is mainly associated with ground materials found beneath the surface litter of the forest floor, such as duff, musk, or peat. Surface fires spread quite rapidly and mostly depend on little plants and litters of the forest. The crown fire spreads the tops of trees and plants without coming into contact with surface fire. All of these types of fires can be spotted in the forest sections of Uttarakhand's Almora district.

14.3 Database

This study has been carried out systematically to analyze the trend and patterns of forest fires and identify the forest fire hotspots. The entire database of the research area was collected from various sources and agencies related to the forest department. In this study, remote sensing plays a vital role in detecting the active forest fire locations through the forest fire signals from the MODIS (Moderate Resolution Imaging Spectro-radiometer) sensor on board Terra and Aqua satellites. This study has utilized historical incidences data of forest fire to analyze the trend and pattern of forest fire and identified the region of forest fire occurrences within the study area. The information on the forest fire incidents is used as point data. These point data sets were collected from the forest survey of India (FSI) in the MS Excel file for the period of 2001–2018. Data were prepared and processed to analyze the dynamics of forest fires in Almora district using GIS and remote sensing.

14.3.1 Methodology

In this study, the historical event data of forest fires, known as event data or point data, has been used to analyze the dynamics of forest fires at three levels of variability in forest fires. On the first level, the forest fire trend was analyzed through the occurrences of forest fires, second patterns of forest fires have been identified with the help of kernel density, and the last hotspot of forest fires has been evaluated by the Getis-Ord Gi* method of hotspot analysis. All these processes were executed with the help of the MS Excel package and ArcGIS package. The study map was prepared for the extracting of the administrative boundary of Almora district by using the toposheet of Uttarakhand state at the scale of 1:1,000,000. This topographical map was collected from the Survey of India. The study map of Almora district was generated by georeferencing and digitizing techniques in ArcGIS 10.3.

14.3.2 Land Use/Land Cover Map Preparation

The open-source Landsat 8 OLI image (geometrically and radiometrically corrected) of November 24, 2016, was obtained from the USGS Earth Explorer (https://earthexplorer.usgs.gov/) as the satellite database to prepare a land use/land cover (LULC) of the study area. The obtained image was classified applying the supervised classification with a nonparametric rule. Finally, the LULC map was prepared with five LULC classes: built-up area, forest land, barren land, water bodies, and agricultural land (Fig. 14.2). For accuracy assessment, a sum of 350 ground-truth points was identified distributed randomly over the study area. The accuracy of the

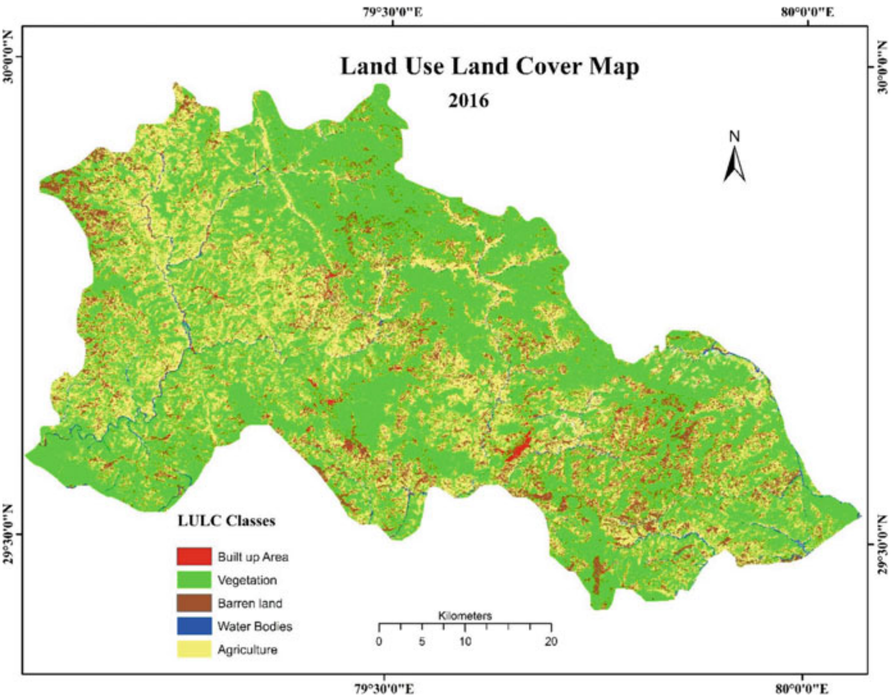

Fig. 14.2 LULC map of Almora district (2016)

classified map was computed after preparing a confusion matrix based on the ground-truth points and after determining the corresponding statistical agreement of kappa coefficient.

14.3.3 Forest Canopy Density (FCD)

The four indexes, namely, Advanced Vegetation Index (AVI), Bare Soil Index (BSI), Shadow Index (SI), and Thermal Index (TI), were used to calculate the forest canopy density that represents the status of forest cover in the study area. All these indexes were based on the Landsat 8 OLI satellite imagery. The FCD of Almora district was derived for identifying different types of forest covers in terms of their density. Four types of forest covers were identified on the basis of canopy density of the forest, namely, very dense forest, moderately dense forest, open forest, and non-forest classes, respectively (Fig. 14.3).

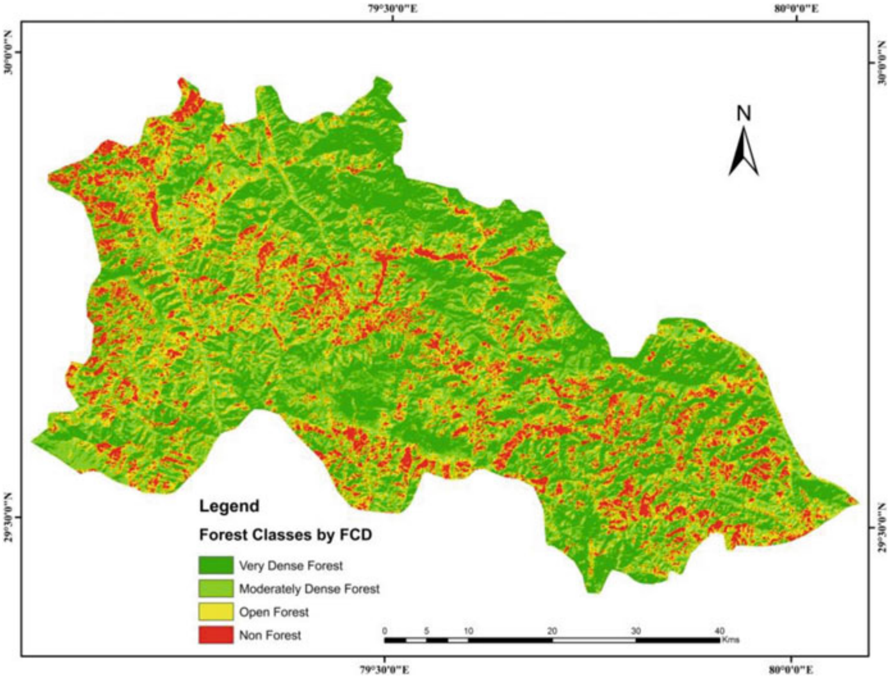

Fig. 14.3 Canopy cover density showing forest classes in Almora district

14.3.4 The Trend of Forest Fires

The date, time (starting time), and location (longitude degree and latitude degree) data about forest fires were obtained from the table of forest fire point file in reference to the year-wise and month-wise forest fires (Ashutosh and Satendra 2014; Doerr and Santín 2016; Dogra et al. 2018; Drobyshev et al. 2021; Koutsias et al. 2014; Vadrevu et al. 2019; Vilar del Hoyo et al. 2011; Yang et al. 2013).

The forest fire trend has been analyzed in context to year-wise, month-wise, and day-wise between 2000 and 2018 that helps to understand the spatial and temporal pattern of forest fires. All these trends were analyzed using quantitative statistical techniques in MS Excel package. These techniques have shown different angles of forest fire occurrences with the help of graphs, bar diagram, and pie chart that are very significant in the study of the dynamics of forest fires in the context of Almora district.

14.3.5 Spatial Pattern of Forest Fires

In statistics, the kernel density approach produces a smoother effect and is more suited to mapping spatial pattern of point distribution. For producing forest fire occurrence maps, the kernel density estimation approach, a nonparametric statistical method, has highly been recommended by researchers. The common definition of kernel density estimation is elaborated as if $X_1, \ldots, X_n$ are the locations of the n observed events, then the value f(x) at location X is estimated by Erran Seaman and Powell (1996), Kuter et al. (2011), Liu et al. (2010), Monjarás-Vega et al. (2020), and Vilar del Hoyo et al. (2011).

$$\widehat{f}(x) = \frac{1}{nh^2} \sum_{i=1}^{n} K\left\{\frac{x - X_i}{h}\right\}$$

where K defines the size of the kernel and determines the degree of smoothing of the density estimate result and $x - X_i$ denotes the distance between the observed point at location X and the point at location X_i. The normal distribution function is the most usually used K, but triangular and quartic functions can also be utilized. However, the bandwidth value is a crucial smoothing element that has a direct impact on the estimation outcome.

The point density module (kernel density) of the Spatial Analyst tool in ArcGIS was used. It derives a magnitude of 1000 per unit area from point characteristics within each cell's neighborhood. The density of forest fire occurrence map has been prepared based on the different time-series data of the forest fires between 2001 and 2018. The kernel density tool was run to generate the map of the density of fire occurrence with the help of fire point data. Finally, the maps that were generated reflected the pattern of forest fire and regions of fire occurrence.

14.3.6 Getis-Ord Gi* Hotspot Analysis of Forest Fires

In this study, Getis-Ord Gi* hotspot analysis method was used to identify the hotspot areas of forest fires in the study area (Cáceres 2011; Chen and Yang 2018; Gajovic and Todorovic 2013; Mpakairi et al. 2019; Padalia and Mondal 2014; Potter 2009). This hotspot analysis utilizes Gi* statistics that can be calculated as follows:

$$Gi^* = \frac{\sum_{j=1}^{n} w_{ij} x_j}{\sum_{j=1}^{n} x_j}$$

where *Gi** denotes the spatial autocorrelation (spatial dependency) statistics of an event *I* across *n* events, *xj* is the magnitude of variable *x* at events *j* across all *n*, and *wij* denotes the weight value between events *I* and *j* that denotes their geographic interrelationship. *Gi** statistics assumes the size of each feature in the dataset in relation to its neighbors' values.

Getis-Ord Gi* hotspot analysis determines the features that tend to concentrate with high and low Z-scores. The analysis tool computes a Z-score for each feature, which can be used to identify event cold and hotspots. The statistical significance of clustering for a given distance is represented by the Z-score output. The details of the methods adopted in the present study are given in Fig. 14.4.

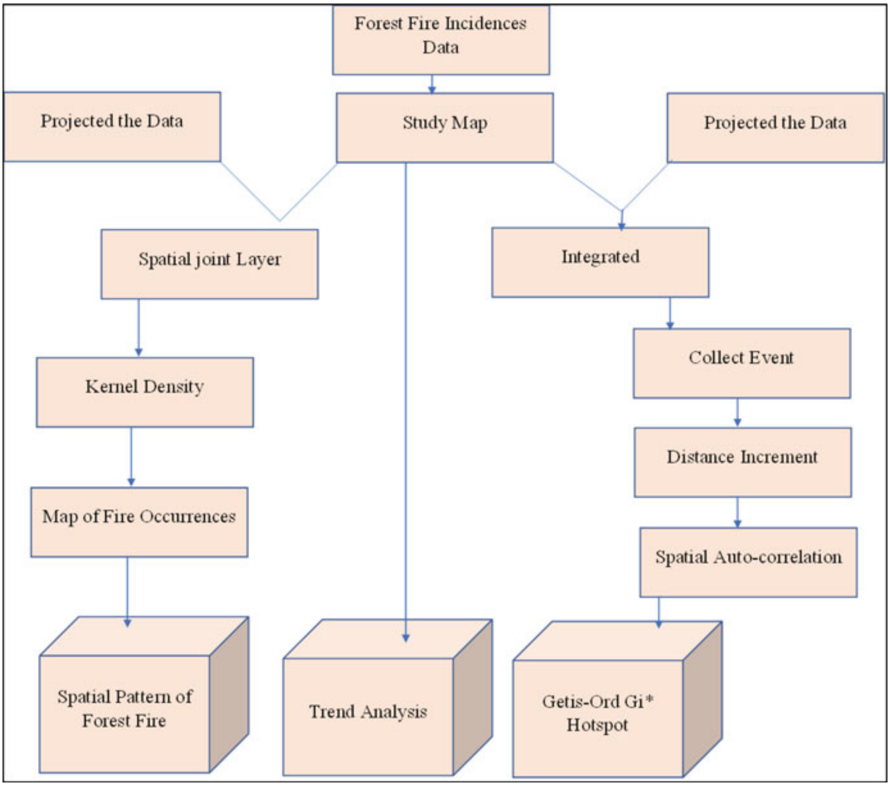

Fig. 14.4 Flowchart showing the overview of methods adopted in the present study

14.4 Results and Discussion

14.4.1 Results of Accuracy Assessment

The results of the accuracy assessment obtained in the present study are given in Table 14.1. The total accuracy of the LULC classification was 81.33%, whereas the producer's accuracies and user's accuracies for the LULC classes ranged from 69.14 to 100% and from 58.33 to 93.33%, respectively. The corresponding overall kappa coefficient was found to be 0.7667, ranging from 0.5283 to 0.9087 for the LULC classes (Table 14.1). Therefore, the degree of overall agreement found in the present classification was substantial and satisfactory (Fielding and Bell 1997).

14.4.2 Results of LULC Classification

Class-wise areas for the LULC classes obtained from the image classification are given in Table 14.2. Forest cover accounts for 1719.86 sq.km in the study area, covering 54.79% of the district. Agricultural land occupies about 948.29 sq.km and 37.84% of the district's total area. Barren land covers 325.51 sq.km and 10.37%, whereas water bodies represent 50.85 sq.km and 12.85% of the total areas of the district. The built-up class covers about 94.48 sq.km area, which occupies 3.77% of the district. Thus, forest area was identified as the dominant land cover type,

Table 14.1 Details of accuracy assessment of the classified image of Almora district (2016)

LULC classes	Producer's accuracy (%)	User's accuracy (%)	Kappa co-efficient
Agricultural land	81.97	83.33	0.7908
Water bodies	100.00	58.33	0.5283
Barren land	78.79	86.67	0.8291
Forest land	69.14	93.33	0.9087
Built-up	89.47	85.00	0.8148
Overall accuracy	81.33%		
Overall kappa	0.7667		

Table 14.2 LULC class-wise areas in Almora district (2016)

LULC classes	Class areas (sq. km)	Percentage cover (%)
Forest	1719.86	54.79
Agricultural land	948.29	30.21
Barren land	325.51	10.37
Water bodies	50.85	1.62
Built-up	94.48	3.01
Total	3139	100

Table 14.3 Forest classes and their corresponding areas in Almora district

Classes	Area (aq. km)	Percentage (%)
Very dense forest	397.35	12.65
Moderately dense forest	853.53	27.19
Open forest	790.11	25.16
Non-forest	1098.54	34.99
Total	3139.00	100.00

accounting for 55.87% of the total area of Almora district, followed by agricultural land, barren land, built-up area, and water bodies, respectively, as represented in Table 14.2.

14.4.3 Forest Cover and Classes by FCD

The FCD analysis shows that the district of Almora is dominated by very dense forest, followed by moderately dense forest, open forest, and non-forest classes, respectively (Fig. 14.3). Table 14.3 shows different forest classes and corresponding areas derived from the FCD analysis. The table shows that the very dense forest cover is about 397.35 sq.km and 12.65%; moderately dense forest accounts for 853.53 sq.km and 27.19%; and open forest occupies 790.11 sq.km and 25.16% of the total areas under the district (Table 14.3)

14.4.4 Overall Forest Fire Assessment

The district of Almora reported a total occurrence of 7380 forest fires from 2001 to 2018. Broadly four major forest fire occurrence regions were identified in Almora district. During 2001–2018, the forest fire regions were found in the northern, north-east, south-east, southern, and south-west part of Almora district. It has shown a very compact pattern of forest fire in Almora district. Some photographs of forest fires in the study area captured during the field survey are given in Fig. 14.5.

14.5 The Trend of Forest Fire Occurrences

14.5.1 Year-Wise Forest Fire Occurrences

In this study, the trend has been carried out from the year-wise analysis of occurrences of forest fire of Almora district for the period of 2001–2018. Table 14.4 shows year-wise forest fire occurrences in the study areas.

Fig. 14.5 Some photographs showing the incidences of forest fire in Almora district

Table 14.4 Year-wise forest fire occurrences in Almora district

Year	Number of fire occurrences	Percentage	Difference	Growth rate in %
2001	27	0.37	NA	NA
2002	76	1.03	49	181.48
2003	534	7.23	507	667.11
2004	506	6.85	479	89.7
2005	242	3.37	222	43.87
2006	75	1.02	48	19.28
2007	104	1.41	77	102.67
2008	461	6.24	434	417.31
2009	665	9	638	138.39
2010	424	5.74	397	59.7
2011	27	0.37	0	0
2012	1583	21.44	1556	5762.96
2013	78	1.06	51	3.22
2014	455	6.16	428	548.72
2015	175	2.34	148	32.53
2016	1229	16.64	1202	686.86
2017	281	3.8	254	20.67
2018	438	5.93	411	146.26
Total	7380	100		

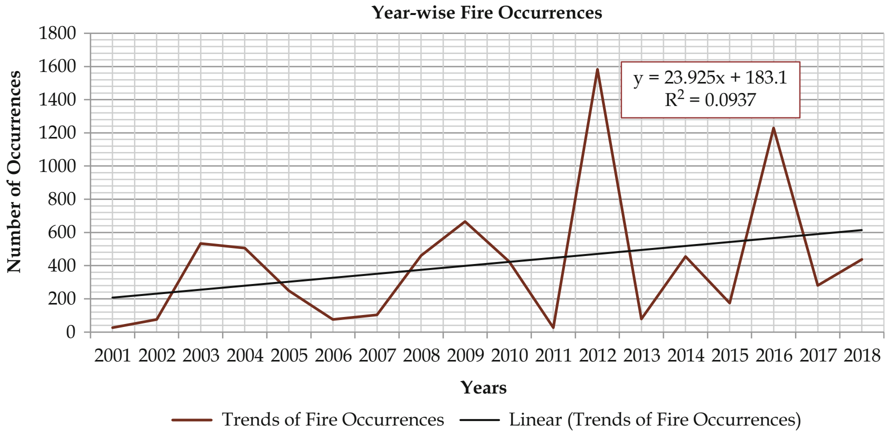

Fig 14.6 Trend depicting year-wise forest fire occurrences in Almora district

The annual incidence of forest fire occurrence in Almora district from 2001 to 2018 has been represented in Fig. 14.6. The trend in forest fire occurrence has increased considerably during the period of 18 years during 2001–2018. In this study period, total incidents of forest fires were 7380, out of which 1583 forest fires were noticed in 2012. The trends of forest fire occurrences can be easily understood from Fig. 14.6.

In Almora district, the years 2012 and 2016 show unexpected trends with the highest frequency of fire occurrences. In the Almora district, the years 2012 and 2016 show unexpected tendencies with the highest occurrence of fire events. The number of two extreme fire incidents can be counted in unexpected trends within the study area in a rapidly changing scenario. The first extreme fire happened in 2012, while the second happened in 2016 (Fig. 14.6). It means forest fire occurrences play a vital role, giving alarming instruction to control the forest fire occurrences in the study area. The average of fire occurrences has been calculated at 410 per year. The growth rate has been identified as very dynamic, with a peak level of 5762.96 in 2012 and an off-peak level of 0 in 2011 (Table 14.4). This growth rate shows a percentage change in fire occurrences from 2001, indicating the dynamics status of forest fires in Almora district.

14.5.2 Month-Wise Forest Fire Occurrences

Month-wise occurrences of forest fires in the study area during 2001–2018 are presented in Fig. 14.6. The trend of forest fire occurrences was found higher in the summer and spring season (March to June) than the other seasons throughout the year. Moreover, the trend of forest fire occurrences was very low in the winter season (December to February) and no fire in the rainy season (from July to September).

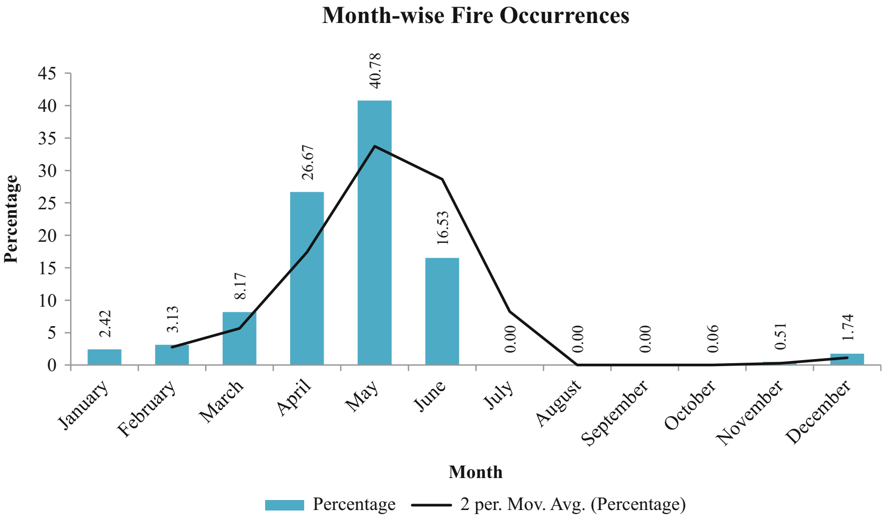

Fig. 14.7 Trend of month-wise forest fire occurrences in Almora district

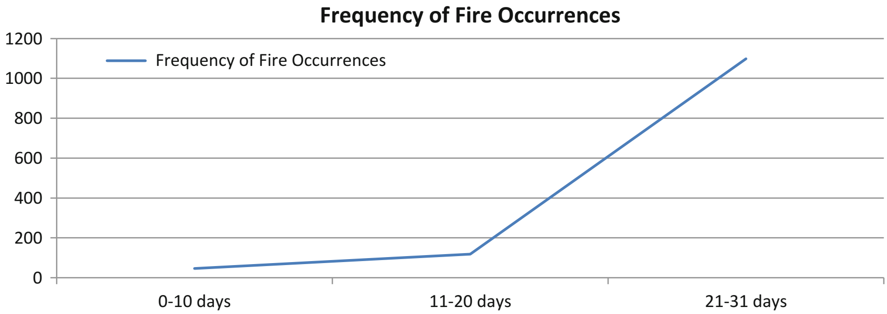

Fig. 14.8 Day-wise trend of forest fire occurrences in Almora district

In May, occurrences of forest fires were maximum, followed by June, April, and January. The lowest number of fires was found in June. There were 2970 forest fires in May, out of which 7380 were found during this study period. Figure 14.7 shows the month-wise density of fire occurrences for 2012 in Almora district.

14.5.3 Day-Wise Forest Fire Occurrences

The day-wise analysis of forest fire occurrences in May in Almora district is presented in Fig. 14.8. The trend of forest fire occurrences was found higher during the later days than the other days in May.

14.6 Spatial Pattern of Forest Fires

14.6.1 Year-Wise Spatial Pattern of Forest Fires

In this study, the year-wise pattern of forest fire was analyzed in three different years (2001, 2010, and 2018) of forest fire occurrences in Almora district during 2001–2018 (Figs. 14.6, 14.7, and 14.8). The pattern of forest fire was carried out from the density of forest fire occurrence maps for identification of the region of occurrences of forest fire within the Almora District Boundary. All these maps have their characteristics. Details of the color scheme on map are as follows:

Green color shows "no fire."
Yellow color shows "moderate fire."
Red color shows "high density of fire."

14.6.1.1 Forest Fire in 2001

In this study, the pattern of forest fire was analyzed from the forest fire density map. In this map (Fig. 14.9), the density of fire occurrences was much less and was the dominant green color. A single red color patch was visible. All these characteristics have shown the limited area of the density of forest fire within Almora district in 2001. This dense region was found in the southern part of Almora district.

14.6.1.2 Forest Fire in 2010

The pattern of forest fire in 2010 has more extent compared to 2001 pattern. In the 2010 map (Fig. 14.10), the fire occurrence density has increased, denoting too many red and yellow patches. One major region of occurrence was identified in the northern part of Almora district, and many short patches were found in the northwest, northern, northeast, southeast, southern, and southwest parts of Almora district. A scattered pattern of forest fire was found within Almora district in 2010.

14.6.1.3 Forest Fire in 2018

In the 2018 map (Fig. 14.11), red and yellow color patches have increased in size, showing an increased density of fire occurrences and expansion in the region of forest fires. In the 2018 map, the density of fire occurrence has increased, showing many patches of red color and yellow color.

At this time, one major fire occurrence region with more extent was identified in the northern part of Almora district, and some regions were found in whole parts of Almora district. A compact pattern of forest fire was found within Almora district in 2018. The dominance of the green color has decreased significantly on the maps

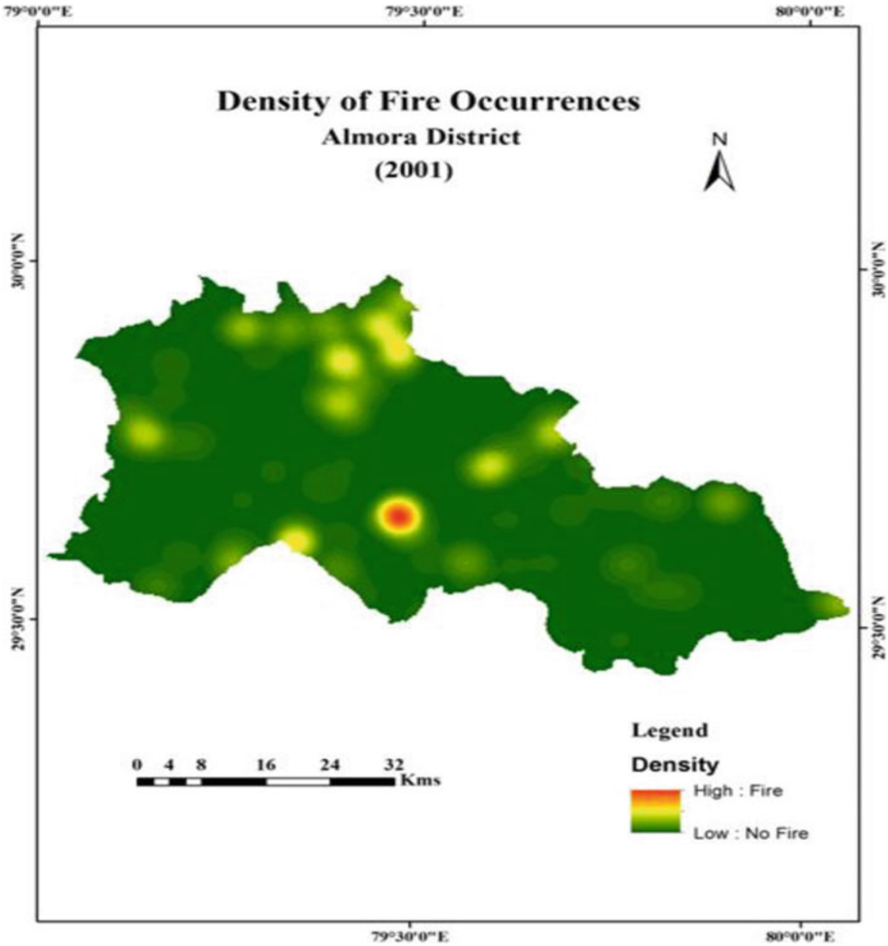

Fig. 14.9 Pattern of forest fire occurrences in Almora district in 2001

during the period 2001–2018. Several major regions of fire occurrence were carried out within Almora district. All these regions were identified in the north-west, northern, north-east, south-east, southern, and south-west parts of Almora district. In 2018, a compact pattern of forest fire was shown within Almora district.

14.6.2 Month-Wise Spatial Pattern of Forest Fires

In Figure 14.12, a month-wise spatial pattern of forest fire in Almora district has been evaluated for the year 2012. The maps of January, February, March, April, May, and June show an increase in the density of fire occurrences in Almora district. The maps

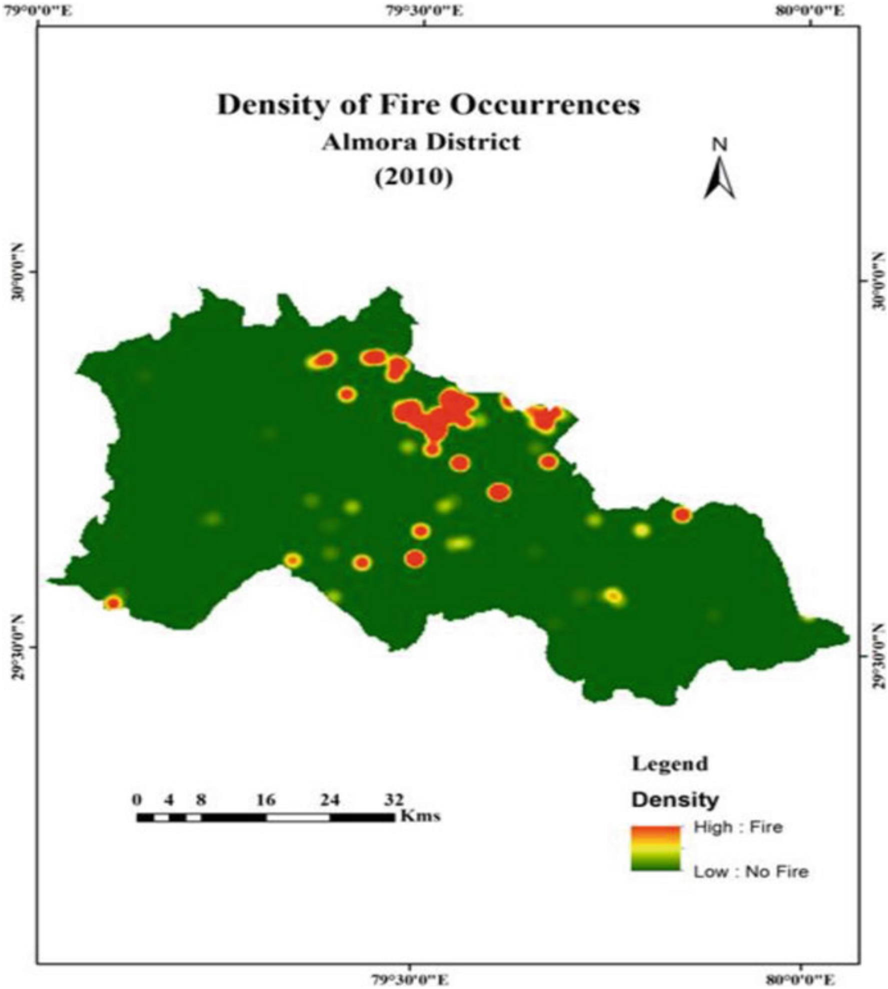

Fig. 14.10 Pattern of forest fire occurrences in Almora district in 2010

of November and December show less density of fire occurrence. In Almora district, the pattern of forest fire occurrences has been identified during March to June as a stronger form compared to another month. In the March to June period, the density of fire occurrences was noticed through the red and yellow color patches.

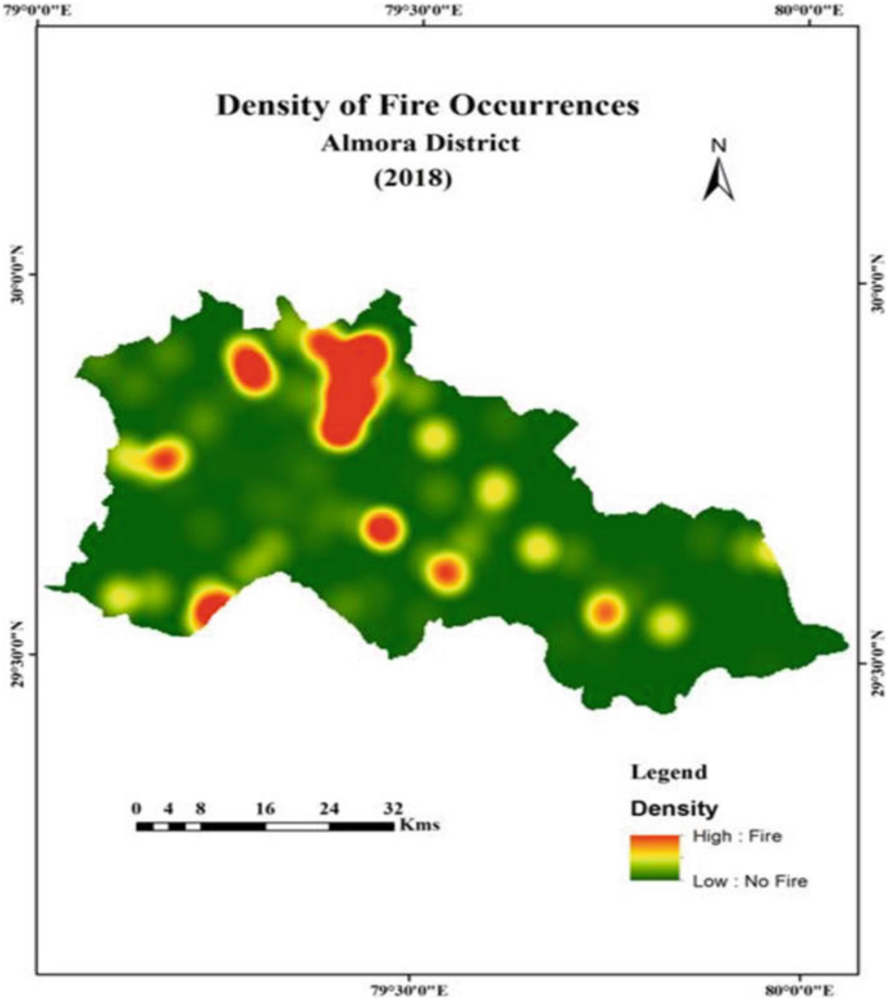

Fig. 14.11 Pattern of forest fire occurrences in Almora district in 2018

14.6.3 Day-Wise Spatial Pattern of Forest Fires

In Figure 14.13, the day-wise pattern of forest fires is shown for May 2012 with categories 0–10 days, 11–20 days, and 21–31 days. In the map of 0–10 days, the pattern of fire occurrences identified shows limited extent in the northern parts of Almora district, and in 11–20 days, the pattern of fire occurrences expands to other parts, viz., northern, northeast, southeast, and southern of Almora district. Lastly, during 21–31 days, the pattern of fire occurrences became prevalent throughout Almora district, viz., northern, northeast, southeast, southern, and southwest parts.

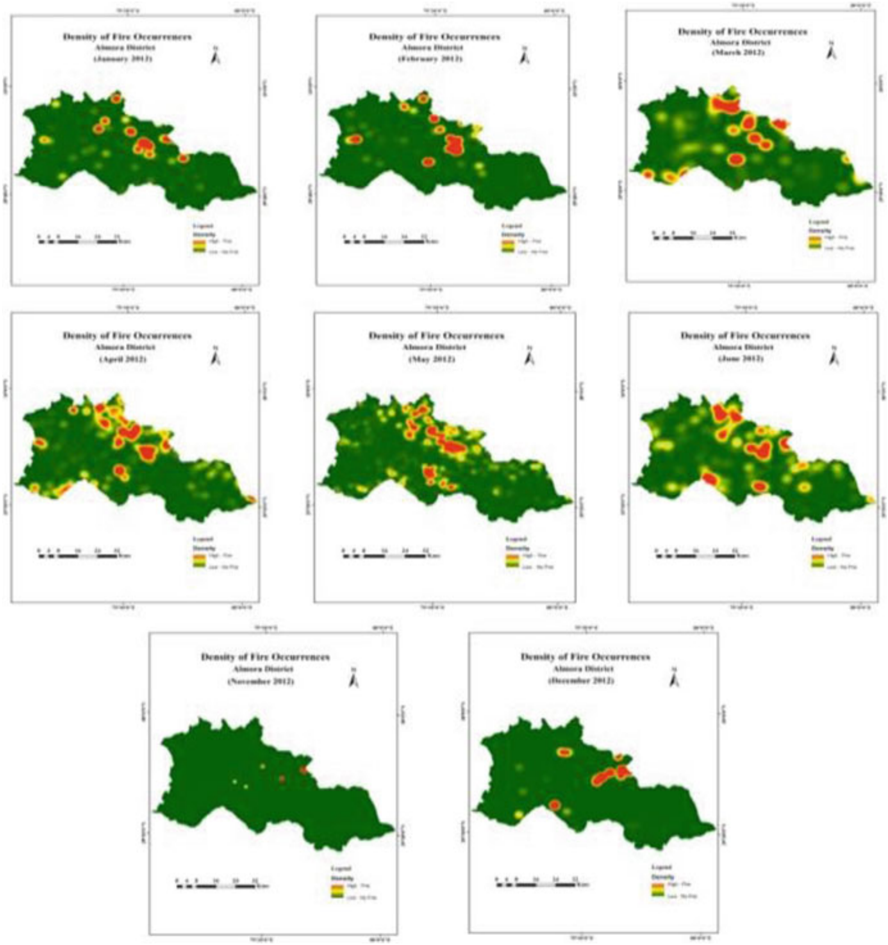

Fig. 14.12 Month-wise patterns of forest fire occurrences in Almora district (2012)

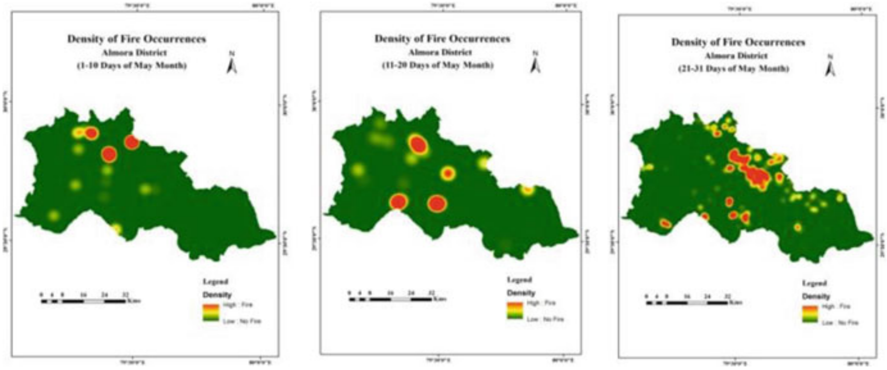

Fig. 14.13 Day-wise patterns of forest fire occurrences in Almora district (2012)

14.6.4 Getis-Ord Gi Hotspots of Forest Fires*

Figure 14.14 shows the intensity of total forest fire occurrences in Almora district without applying Getis-Ord Gi* tool, and Fig. 14.14 shows the outcome of the Getis-Ord Gi* tool showing the intensity of forest fire occurrences. In the study area, this tool has provided the output in the context of the Gi Z-score map that denotes the cold and hotspots. In addition, it formulated point features colored as red and blue which represent significant cold and hotspots, respectively, cream-colored points representing nonsignificant spots in the study area (Fig. 14.14).

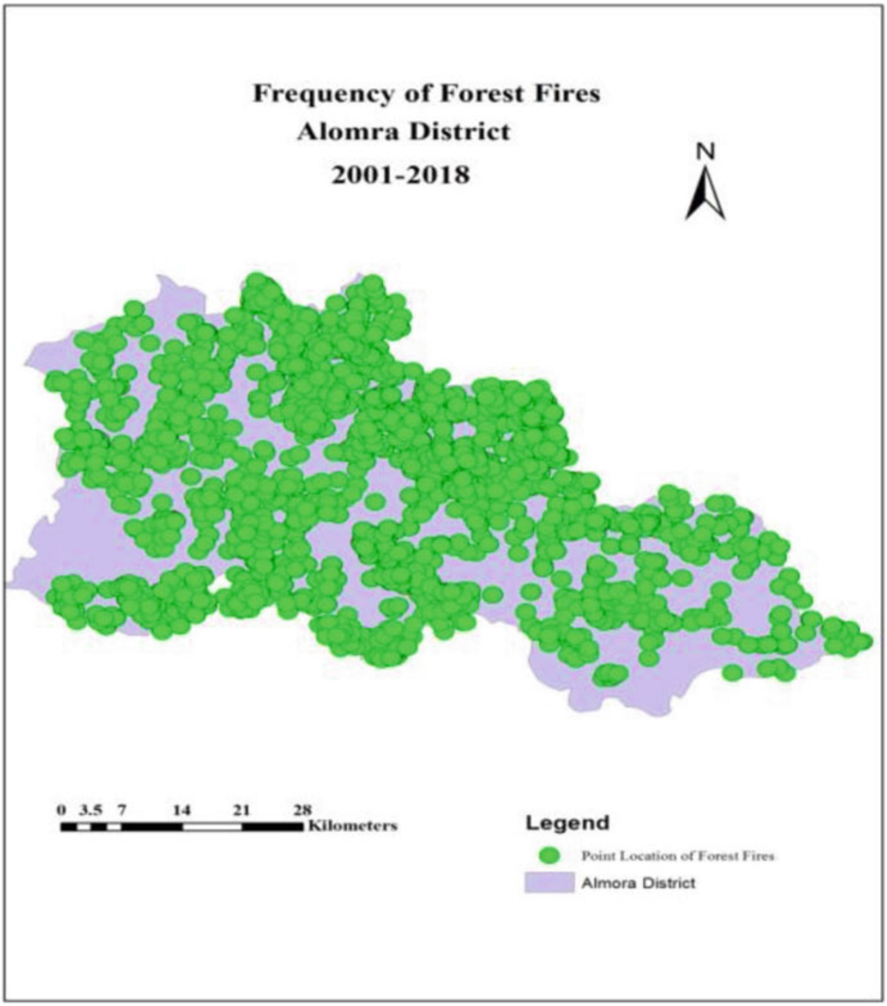

Fig. 14.14 Location of forest fire occurrences in Almora district during 2001–2018

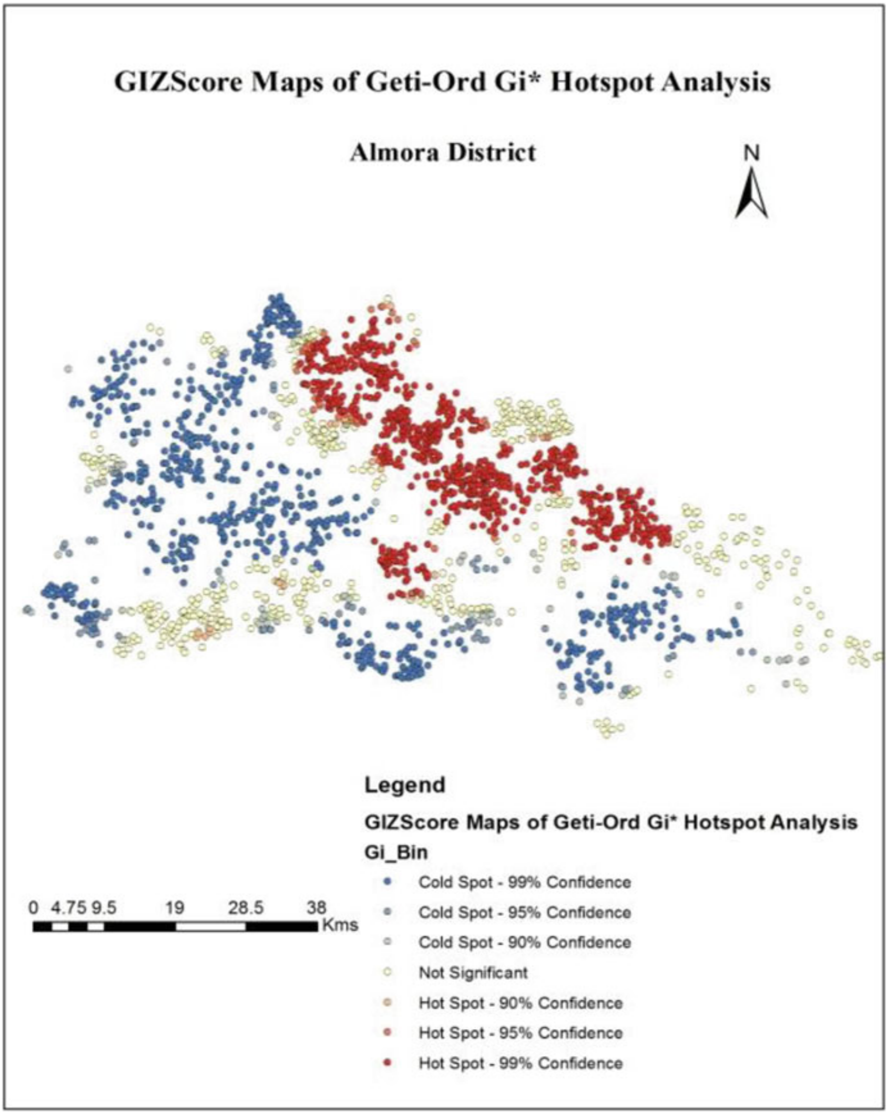

Fig. 14.15 GI Z-score map of Getis-Ord Gi* hotspot analysis

An output of Gi Z-score was produced using this tool, which formulates Z-score values that serve to demonstrate the statistical significance of feature clusters: the cold and hotspots (Fig. 14.15). It is observed that cold spots and hotspots are represented by points with standard deviations of $-1.209978 < z < -0.203445$ (blue) and $1.576269 > z > 0.303554$ (red), respectively. It also reveals that features with a low Z-score are designated as cold spots (blue), and features with a high positive *Z*-score are designated as hotspots (red). The *Z*-score is used to determine if the features suggest a clustering pattern or statistically significant random or dispersion, implying that a spatial mechanism was at work. As a result, a statistically significant positive *Z*-score (i.e., a higher value) suggests intensive hotspot clustering, while a statistically significant negative *Z*-score (i.e., a lower value) shows strong cold spot clustering in the study (Fig. 14.15).

Whereas the Getis-Ord Gi* method was used to build the hotspot map, the inverse distance weighted (IDW) approach was used to visualize the hotspots. IDW is the most extensively used interpolation technique for determining the spatial extension of hotspots. On the forest fire hotspots scattered throughout the research area, it forms smooth continuous surfaces. As illustrated in the diagram, the continuous smooth surface has been separated into five different classes of hotspots, as shown in Fig. 14.16. In Fig. 14.16, the very high red-colored areas indicate a zone of higher forest fire occurrence, which necessitates more attention from local government and rescue services in managing forest fire occurrences since forest fires are more concentrated in those areas with a high *Z*-score. The very low areas (blue colored) on the other hand indicate a statistically significant clustering pattern with a negative *Z*-score, and these places require the least care because they are forest fire cold spots. High, moderate, and low-risk zones, on the other hand, require varied levels of attention for forest fire management based on the frequency of fires in these areas. The red zones refer to areas with significant spatial clustering that have a very high value of Z-scores and blue zones have very low *Z*-score values. In addition, Fig. 14.16 shows that forest fire hotspots were identified in the form of high intensity in the north-central part of Almora district, whereas the cold spots are more concentrated in the eastern and western parts of the district. The moderate intensity of spots was also seen in the northern part and a smaller patch in the central and western side of the study area.

14.7 Conclusions

A forest fire can harm the biome and directly repair the forest's biotic diversity. Forest fire is a global problem that has attracted the attention of environmental scientists, planners, researchers, academicians, and others who have investigated and examined its numerous elements and effects on forest life and public property. This study examined forest fire occurrences at the district level in India and identified the extreme location of forest fire occurrences as well as their historical pattern. In this study, the density of forest fire events was also examined using the kernel density approach. This study discovered that fire occurrences had increased significantly during the study period (2001–2018). In particular, the years 2012 and 2016 exhibit unexpected tendencies. The forest fire pattern is very dynamic at the district level. It signified the permanent forest fire occurrences in Takula, Chaukhutia, and Dwarahat blocks and the highly impacted forest fire zone in northeastern and certain sections of It denoted the permanent forest fire occurrences in Takula, Chaukhutia, and Dawarhat blocks, as well as the heavily impacted forest fire zone in the northeastern and southern Almora districts.

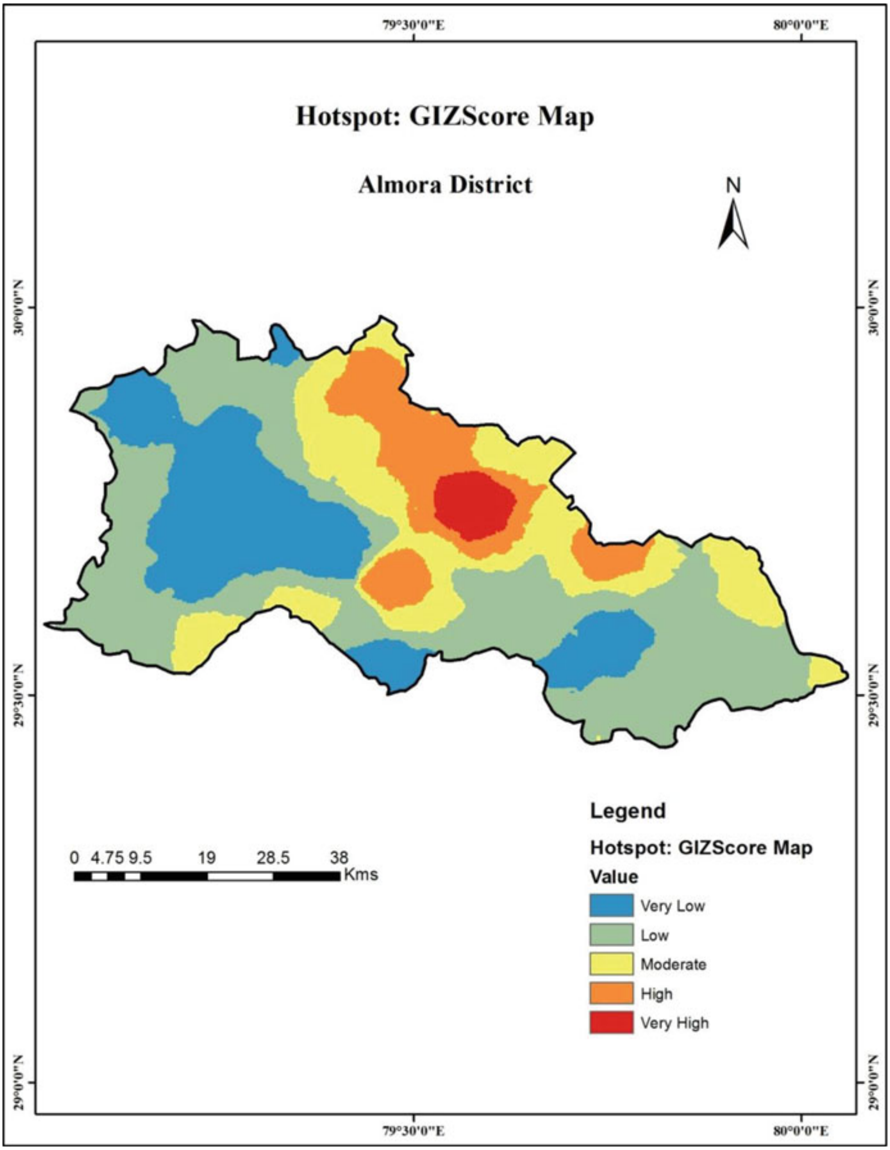

Fig. 14.16 Hotspot of GI Z-scores in Almora district

The summer months saw the highest number of forest fires. Following the year 2010, the frequency of fire incidents increased for the months of November and December, which is getting attention due to climate change. The month of May has been classified as a very high-risk season for forest fires that focus on human activities at the district level.

This study utilized fire data from 2001 to 2018 to examine the distribution of fire hotspot locations in Almora district. The point density (kernel density) map shows the historical forest fire occurrences in the district. The Getis-Ord Gi* analysis was performed to identify a high clustered pattern and construct the fire hotspot map in the research area using spatial statistics analysis. The following conclusions were drawn from the findings: first, the spatial distribution of fire locations was recorded in a clustered pattern, relatively low in 2001. Second, the fire hotspot denotes a higher dangerous area within the district. Finally, the findings can provide significant insights for governments in regional planning and land development and aid in the planning and control of forest fires and the required resources for firefighting.

Forest fire hotspot analysis is necessary for estimating the biodiversity, wildlife, people, and property in danger (Jain et al., 2021). This paper discusses the primary approach of dealing with regular forest fires. The identification of hotspots helps in identifying the intense and frequent spots of forest fires. Thus, proper knowledge about forest fire areas can minimize the incidents of forest fires. GIZ-score map encourages the reduction of forest fires areas. Therefore, it helps support various agencies' management and planning schemes and protects people from this disaster. Landscape, Climate, and Cultural vulnerability of forest fire has been achieved more accurate results with the help of trend, pattern, and GIZ-score Hotspot map. After this research study, various reduction practices can be easily applied such as establishing suitable sites of fire stations, installation of fire watchtower, and identifying the right time to detect the fires in forest areas by identifying fire hotspots. Community participation becomes easy and the spread of forest fire is highly controlled which helps the whole society. This study motivates more studies on various aspects of forest fire for monitoring and prevention policies in forest fire assessment. Thus, there is an urgent need for the government to develop and implement a forest fire policy that also takes into account wildlife and the socioeconomic conditions of the local residents.

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Chapter 15
Approaches and Methodologies on Mapping Vegetation Cover and Biodiversity Status Using Remote Sensing and Spatial Analysis: A Systematic Review

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Abstract Mapping vegetation cover and biodiversity status using remote sensing and spatial technologies has transformed the field of natural resource management. As anthropogenic activities have led to unprecedented changes in biodiversity and vegetation cover throughout the world, these technologies have become very significant in impact assessment and management of these natural resources. Various methods have been used in vegetation and biodiversity mapping especially using remote sensing and special techniques, but there are few review studies covering the entire field of vegetation and biodiversity mapping. The present study has reviewed the various methods and approaches used for mapping vegetation cover. It has tracked its evolution since geospatial technologies have been used for the first time in mapping vegetation till today when advanced models like decision tree and redundancy analysis are being used. This study has used a systematic review protocol for a set of 70 peer-reviewed case studies, which highlight the key analysis, trends, and research paths that have emerged since the evolution of geospatial

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techniques. The study has also examined the emerging trends and gaps in the existing research on vegetation mapping and biodiversity status. The paper is framed in such a way that its first part deals with the conceptual framework of vegetation mapping and biodiversity status. This part also deals with some related case studies on the important biodiversity regions of the world. The second part of the paper discusses the methods, models, databases, and approaches used in vegetation mapping and biodiversity status in selected case studies. The prime objective of the study was to outline the future trends in vegetation mapping. The review study concludes that vegetation mapping studies throughout the world are primarily case studies by their very nature. These case studies have in many ways become an evolving tool for better conservation and management of forest and biodiversity.

Keywords Forest · Biodiversity · Geospatial techniques · Vegetation mapping and land/use

15.1 Introduction

According to Article 7 of the Convention on Biological Diversity, United Nations Conference on Environment and Development (UNCED), the signatories of UNCED need to identify components of biodiversity that can be used for conservation and sustainable use and monitor them through sampling and other techniques. As regards the development of relevant methodologies, Chapter 15.6 of the UNCED document calls upon the parties to undertake systematic evaluation on a nationwide basis for the identification of biodiversity components and develop these via new methodologies and start/continue the work on surveys at the appropriate level on the status of ecosystems to establish baseline information on biological resources. Being a signatory, India too has taken several initiatives in this regard. As one of the most biodiverse countries in the world, identification and quantification of all such components has become an enormous task, needing a huge effort. The knowledge on the distribution of vegetation types provides key inputs into planning at the national level for food security, conservation of different habitats for wildlife, promoting the sustainable management of natural resources, agroforestry, and the conservation of biodiversity hotspot areas (Roy et al. 2012). Furthermore, this knowledge particularly helps in conserving ecologically sensitive and protected areas and in developing forest corridors.

Various approaches and methods have repeatedly been used for mapping vegetation cover at different scales and for different purposes, especially after the evolution of remote sensing and GIS techniques and technologies over the last few decades. However, there are very few wide-ranging reviews of this field that document such exercises and its future trends. So this article aims to present a comprehensive portrayal of the previous works related to mapping vegetation cover and biodiversity status across the world. The paper has been divided into two sections. The first section deals with the conceptual framework of vegetation mapping and has some related case studies on the important biodiversity regions of the world. The second section is devoted to collating and relating the methods, models, databases, and approaches used in such evaluations. Through this, a major objective of this study is to outline the future trends in vegetation mapping.

Increasing anthropogenic activities, both in spatial extent and intensity, have directly and indirectly precipitated unprecedented changes in natural ecosystems and the occurring environmental processes. These alterations have not only resulted in the loss of biodiversity and led to landscape degradation (Reddy et al. 2008; Oladejo 2015; Körner 1998) but have also created almost entirely modified anthropogenic biomes or anthromes (Ellis and Ramankutty 2008). Herein arises the role of land use/land cover (LULC) information and its precise analysis, which provides essential inputs for a large number of management and planning activities, starting from the local to national levels (Oladejo 2015; Körner 2003). This is because the most basic of planning- and conservation-related information, like that of location and the distribution of human and natural resources, is expressed both qualitatively and quantitatively through land use/land cover mapping. The usefulness of vegetation mapping is paramount toward understanding the distribution of various natural and man-made systems, the ecogeomorphology of a region and the crucial ecosystem services provided by it, and its aesthetic quality and vulnerability to different hazards (Townshend et al. 1991; Areendran et al. 2020a; Saha et al. 2020; Das et al. 2021; Mondal and Patel 2021).

However, identification of ambient biodiversity, mapping it, and at the same time monitoring the overall ecological quality, species richness, and its distribution, together with landscape fragmentation that has resulted due to human activities, are quite a complex task (Chatterjee and Patel 2016; Areendran et al. 2020b; Patel et al. 2020; Pokhriyal et al. 2020; Sahana et al. 2015, 2018; Sahana and Ganaie 2017). Hence, to overcome this problem, an array of international and national initiatives have tried to come up with simplified, yet significant, methodologies of biodiversity assessments (e.g., the Biodiversity Information System (BIS) prepared by the Indian Institute of Remote Sensing, Dehradun for India – Roy et al. 2012, 2015a, b). One of the initiatives is the identification of indicators with which to assess the ambient biodiversity, using a subset of attributes that can serves as surrogates for the ecological components of the environment. The initiatives have been progressively developed at all levels – international, national, and regional (e.g., Stork et al. 1997). Furthermore, for biodiversity conservation, it is essential to focus not only on the protection of a single or multiple species but also on the overall conservation of the habitat in general, along with its abiotic environment (i.e., the geodiversity) (Yuan et al. 2005a, b; de Paula Silva et al. 2015; Manríquez et al. 2018). In this scenario, the most suitable way of keeping track of biodiversity is by inventorying and analyzing the vegetation cover (Heywood and Watson 1995; Özyavuz 2013), and a range of landscape metrics and indices have been developed for mapping the same along with their relevant statistical computational methods and softwares (e.g., FRAGSTATS – McGarigal and Marks 1995; Nelson et al. 2015).

15.1.1 Contextual Background

Maps concerned with vegetation reveal the pattern in which the plant communities are positioned in a particular landscape with respect to ambient terrain attributes and local lithological cover, geomorphological forms, and climatic aspects (Sarkar and Patel 2016; Sahana et al. 2015, 2018; Patel and Mondal 2019; Areendran et al. 2020a, b; Mukherjee and Patel 2022). At the same time, such maps also help to create a database of the existing plant communities, along with their location, extent, and geographical distribution in the landscape during the period of mapping (Küchler 1988; Areendran et al. 2020a). To initiate various vegetation protection and restoration programs, one of the most important requirements is the presence of accurate assessment on the present status of the vegetation cover, with this becoming especially important for implementing the range of ecological engineering and live-vegetation-based restoration schemes in watersheds, agricultural landscapes, and urbanscapes for enhancing river health, mitigating soil loss from farmlands, and reducing the deleterious effects of urban expansion (He et al. 2005; Mondal and Patel 2018, 2020, 2021; Chakraborty et al. 2021a, b; Majhi et al. 2021).

A dangerous situation that the world faces at present is that of landscape fragmentation (Hobbs 1993; Sahana et al. 2016, 2018; Patel et al. 2020). In this case, the common goal of the use of satellite data for landscape pattern analysis is the analysis of landscape fragmentation and detecting the temporal changes that have occurred in a landscape due to the gradual replacement of land cover attributes by land use components, leading to their degradation (Chatterjee and Patel 2016; Sahana et al. 2020). Several factors have an impact on the fragmentation of landscape and these alter the behavior of ambient species, their populations, and those biotic communities that are dependent on that landscape, including the spatial arrangement of patches and their different quality and the juxtaposition and proportion of different habitat types (cf. Saunders et al. 1991; Karlsson and Van Dyck 2005; Tremblay and St. Clair 2009; Cline and Hunter Jr 2013; Langley et al. 2018; Latimer et al. 2018; Areendran et al. 2020a; Tolentino and Anciaes 2020). Apart from all these influences, mapping the distributions of vegetation types and land use by humans brings into the picture critical information for landscape management toward formulating a sustainable ecosystem (Helmer et al. 2002).

One of the pre-requirements for developing a strategy for the sustainable management of any ecosystem is the accurate identification and attribution of changes in the vegetation greenness component (Chakraborty et al. 2021b; Mandal et al. 2021). To understand the variation in the pattern of vegetation response in a better way, some of the key requisites are (at all the levels – local to global scale), firstly, to identify the drivers of the carbon sink; secondly, to pre-empt the spatiotemporal dependence of the response of future vegetation; and lastly, to obtain knowledge about the region's ecology via short-term or cross-sectional studies, without which such plans would not be feasible. Vegetation analysis also plays a crucial role in quantifying the various processes occurring on the land surface, e.g., avalanches, landslides, hydrological processes, water quality, soil erosion, and many more

(Myneni et al. 1997a, b; Romshoo et al. 2002a, b; Nelson et al. 2015; Sahana et al. 2015, 2016, 2018; Areendran et al. 2020b). Apart from this, a region's climate is also influenced to a certain degree by feedbacks from its vegetation cover and this also has an effect on the transfer and pathways of nutrients and flow of energy across various trophic levels and on biogeochemical cycling (Claussen and Gayler 1998; Bellard et al. 2012).

The process of relating ecological processes with the spatial patterns of vegetation is one of the basic aims of landscape ecology (Forman 1995; Dragut et al. 2010). In this, the analysis of the landscape pattern or quantifying its spatial heterogeneity is considered as important to understand a range of ecological processes (McGarigal and Marks 1995; Nelson et al. 2015), like competition within interspecies or intraspecies, landscape fragmentation and patch metrics, and other diverse phenomena present in that ecosystem (Turner 1989; Gustafson 1998). Therefore, it has become quite important to gather accurate and specific knowledge about the patterns of vegetation at the landscape scale to discern the cause-effect relationships between vegetation distribution and characteristics of the landscape in order to frame effective and location appropriate conservation strategies (Saunders et al. 1991; Areendran et al. 2020b). Hence, the role of abiotic landscape components and processes and its vegetation cover in terms of influencing the habitat health and quality has gained considerable significance in conservation biology (Riitters et al. 2009a, b; Saha et al. 2020; Mondal and Patel 2021).

In almost all cases, conducting ground-based evaluations to create inventories and maps of native vegetation conditions at the local, regional, and state scales is not practical from the perspective of time, cost, and data temporality and sensitivity, especially for fast reporting or monitoring of changes at the landscape level. Herein arises the crucial role and application of remote sensing techniques and datasets, which can be efficiently and succinctly employed to assess the vegetation coverage and habitat health of an area and pinpoint the factors responsible for the depletion of its biodiversity (Powers et al. 2013; Fernandes et al. 2011; Wasige et al. 2013; Michez et al. 2016a, b; Evangelista et al. 2018; Nguyen et al. 2018; Novoa et al. 2018). In comparison to conventional methods, radar, optical, and thermal remote sensing sensors have proven that they have a much improved accuracy for the evaluation of land surface properties and vegetation attributes (Zhang et al. 2003; Hoekman and Quinones 2000; Pettorelli et al. 2014; Wegmann et al. 2016). Furthermore, the advent of UAV/drone-based mapping and LiDAR technologies and the development of vegetation-specific sensors and machine learning algorithms have further enabled such tasks to be undertaken at short intervals and at very high accuracies (Omasa et al. 2007; Keneko and Nohara 2014; Bertachhi et al. 2019; Bhatnagar et al. 2020; Wang et al. 2020; de Castro et al. 2020; Recently Roshani et al., (2022) have done a systematic review on forest vulnerability to climate change in recent global publication).

For creating a GIS framework for analysis of the natural habitat and landscape, a number of spatial databases on vegetation types and status are now being used (e.g., the BIS in India). Combining ancillary data sources along with spatial and nonspatial information in a GIS platform helps to produce habitat maps that can be used to detect the environmental influences and stressors in different ecosystems so that measures can be taken for habitat conservation (Wilson et al. 2003). In association with simulation modeling, geoinformatics has created a vital toolbox to understand biodiversity richness, pattern of vegetation species distribution, disturbance regimes, causative factors of degradation, and any anthropogenic influences in this regard (Patel et al. 2020; Mukherjee and Patel 2022) integrating all these diverse datasets and viewpoints. The evolving nature of satellite remote sensing technology has served as a powerful tool for monitoring and characterizing vegetation over large temporal and spatial scales, with high repetition and resolution, which has further helped in relating any deviations in their natural pristineness to the respective impairment causes (Fensholt et al. 2009; Brown et al. 2012; Mishra et al. 2015; Kuenzer et al. 2015a, b). Particularly in areas with rugged topography that are inaccessible, remote sensing has been very useful for the exploration of ambient ecology (Uniyal et al. 2002a; b) and in elucidating the intertwined factors that play a role in the distribution, abundance, and species interaction. An important aspect of conservation biology is species richness modeling (Chen and Taylor 2012), which discerns where rich biodiversity sites or ecological hotspots are present toward envisioning strategies for its conservation and gauging any debilitating impacts wrought on such a landscape by climatic change or rising anthropogenic activities. GIS and remote sensing have become vital tools in this regard as well (cf. Iverson et al. 1998; Graham and Hijmans 2006; Sudhakar Reddy 2017; McKerrow et al. 2018).

15.2 Methods

A large number of studies on vegetation cover mapping have been carried out by various researchers using different approaches and techniques. Mapping the distributions of vegetation types and human-modified land cover and land use patterns provides crucial information for managing landscapes in order to preserve biodiversity and ecosystem structure and function (Areendran et al. 2020a; Saha et al. 2020; Mondal and Patel 2021). With manifold advancements in the field of remote sensing and GIS all over the world, various methods and techniques have been repeatedly used for mapping of the existent vegetation cover. An extensive literature survey was carried out in the present study with the aim of presenting a comprehensive portrayal of the trends in mapping vegetation cover and biodiversity status worldwide, primarily using remote sensing and GIS. This can help discern the state of science in this domain, provide knowledge of the latest advancements, and be a valuable starting point for researchers looking to enter this domain.

The present study follows the methods suggested by Ahmed et al. (2021) and Dung et al. (2021), with certain modifications. The methodology was designed by dividing this work into the following stages (Fig. 15.1):

(1) Building the summary of the literature review
(2) Background of vegetation mapping using geospatial techniques

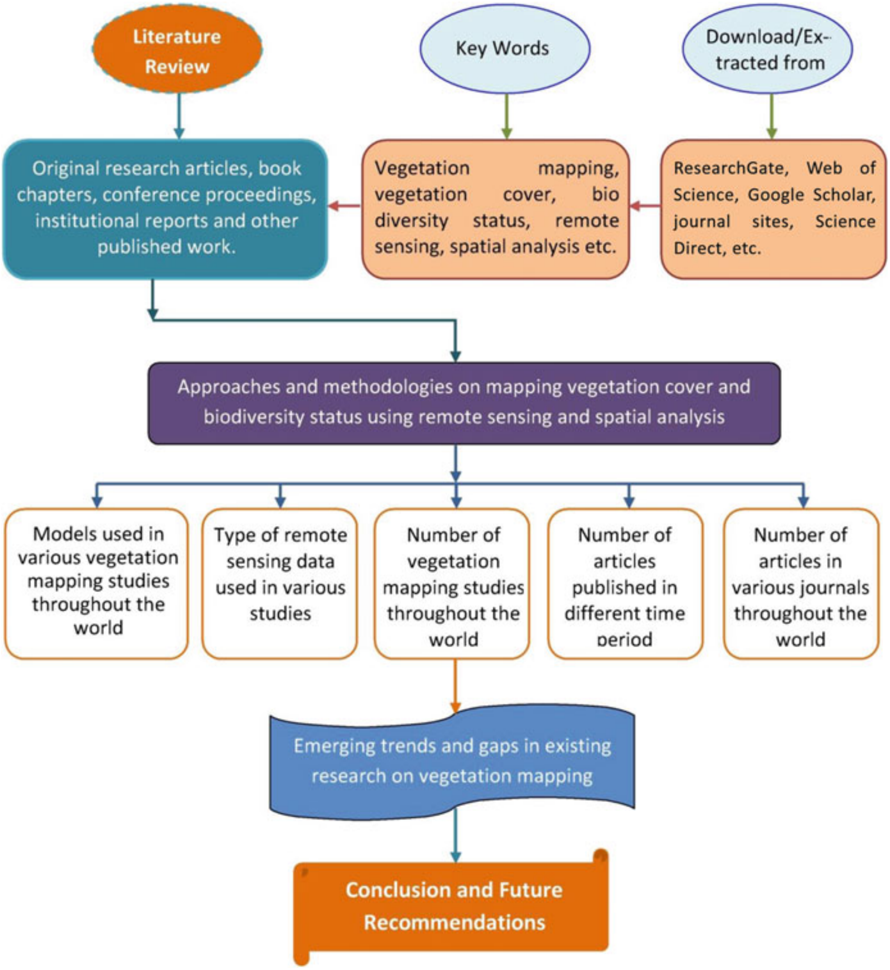

Fig. 15.1 Methodological flowchart

(3) Discerning the common approaches used in vegetation mapping
(4) Type of data and sensors used in vegetation mapping
(5) Distribution of vegetation mapping studies around the world
(6) Number of research articles published in various journals
(7) Conclusions and recommendations

In the first stage, about 70 peer-reviewed research articles, book chapters, conference proceedings, and institutional reports were collected from Internet-based academic repositories and indexing services such as ResearchGate, Web of Science, and Google Scholar and directly from the websites and issues of various relevant journals and scientific publishers. Keywords like “vegetation mapping,” “vegetation cover,” “biodiversity status,” “remote sensing,” and “spatial analyses” were used to extract the research articles published in these domains during 1977–2018. In the second methodological stage, all the approaches and methods relating to vegetation mapping were identified from the above scientific literatures extracted from various Internet-based sources. Most of the articles were derived from peer-reviewed journals such as *International Journal of Remote Sensing*, *Biodiversity and Conservation*, *Environmental Monitoring and Assessment*, *Journal of the Indian Society of Remote Sensing*, *Landscape Ecology*, *Norwegian Journal of Geography*, *Science Press*, *Plant Ecology*, *Wetlands*, and others. The respective abstracts, introductions, methodology, discussions, and conclusions of the selected research papers were reviewed to achieve the aims and objectives of the present study. Finally, the emerging trends and gaps in the existing research on vegetation mapping were identified.

15.2.1 Data Sources and Search Strategy

For this data analysis and bibliometric map creation, the Scopus indexing database was selected as a data source due to its wide reach and use in the academic community. Data mining was performed on July 7 and 8, 2021, by using the Scopus database indexing and search tools. The key search themes used herein were “research articles” in the title and abstract, and for the keyword option we stipulated the phrase “Vegetation Mapping using Remote sensing.” The search results showed the input old and recent time limits of publication, i.e., the years 1970 and 2021, respectively. The query of the search string used was:

TITLE-ABS-KEY (vegetation AND mapping AND using AND remote AND sensing)

The derived output showed a total of 7939 documents. After limiting the query string to only “Article and Journal,” the final result elicited gave a total of 5352 documents. The use of the second search query string was as follows:

TITLE-ABS-KEY (vegetation AND mapping AND using AND remote AND sensing) AND (LIMIT-TO (DOCTYPE , “ar”)) AND (LIMIT-TO (SRCTYPE , “j”))

We then analyzed the content and distribution of the published articles worldwide since 1970, in the 20 best journals. The published documents were selected by year, from 1970 to 2021. A bibliometric map of author keyword co-occurrence and co-authorship countries using overlay visualization mode was applied on the central theme of “Vegetation Mapping using Remote sensing” with the help of Scopus index database and the VOSviewer software.

15.3 Overview of Vegetation Mapping Using Remote Sensing

The increase in human population and its intervention in nature and various natural phenomena have caused an enormous change in land use, with each passing day. Thus, the presence of a valid and reliable database on land use is gaining its due importance in fields like the management of natural resources and landscape planning and biodiversity surveillance programs. The evaluation of the changes in land use has become one of the main components in present strategies for natural resource management and for monitoring ongoing alterations in the environment. Hence, facilitating the environmental managers or the concerned policymakers with a correct assessment of the condition and health of various land-use types like forests, croplands, and grasslands has become one of the priority tasks.

The extent to which natural vegetation is present in a landscape and the quality and robustness of its stands are crucial. It performs several important functions in various operative biophysical processes and markedly influences the ambient terrestrial and climate dynamics (Grace et al. 2006). For all living beings, vegetation provides the base and performs an important role in affecting climate change at the global level like influencing terrestrial CO_2 (Xiao and Moody 2004). By quantifying the vegetation cover, starting from a local to the global scale, over a continuous period or at a particular point of time, and by mapping the vegetation extent, valuable information is derived to understand the human-made and natural environments in a much better way (Franklin 1995). The importance of vegetation mapping lies in the fact that it is quite important to ascertain the present state of vegetation cover in order to frame or commence various projects related to the protection and restoration of the landscape. An example of such kind of a program is the GAP analysis program, undertaken by the US Geological Survey (Riitters et al. 2009a, b). Its fundamental objective is to conserve the floral communities in a better way (http://gapanalysis.nbii.gov/).

Remote sensing provides a practical and at the same time economical means to study changes in vegetation cover, especially over large areas (Yuan et al. 2005a, b), by having the capacity for systematic observations at various scales and is able provide data archives from the present day to several decades back. Because of this advantage, researchers have widely used remote sensing imagery to delineate the vegetation cover from the local to global scale. An example of such a remote sensing-enabled detailed vegetation monitoring program is the International Geosphere-Biosphere Programme, which pioneered land cover mapping on a global scale for the development of the Global Land Cover Characterization (GLCC) database, based on the imaged scenes of 1 km spatial resolution from the Advanced Very High-Resolution Radiometer (AVHRR) in 1992 (Bartholome and Belward 2005). Subsequently, the database of the global coverage Moderate Resolution Imaging Spectroradiometer (MODIS) land cover dataset was released by NASA based on the Terra MODIS sensor's Level 2 and 3 monthly composite scenes. In a detailed review, Jung et al. (2006) has highlighted the various approaches of land cover mapping, as well as their advantages and drawbacks, from the abovementioned global land cover products. Apart from these large-scale global coverage projects, various regional-scale projects like the Pan-European Land Cover Monitoring project initialized in 1996 aimed at creating a 1 km spatial resolution Pan-European land cover database by combining ancillary data with multiple spectral-temporal NOAA-AVHRR satellite images (Rounsevell et al. 2006). Aside from these datasets that are of global- and continental-scale extents, a large number of efforts were taken to map vegetation at the local or national extents. One such example is the USGS–NPS Vegetation Mapping, a joint program between the US Geological Survey and the National Park Service, which started in 1994 with the objective of producing detailed and computerized maps of vegetation for 250 national parks spread throughout the USA by processing Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) imagery, along with ground sampling references. Apart from mapping terrestrial vegetation, remote sensing technology can also be used to map vegetation underwater, which is considered to be a powerful indicator of the health condition of marine and freshwater ecosystems (Roy and Tomar 2000).

Various earlier studies have used images from different sensors like IRS LISS II, LISS III, and Landsat Thematic Mapper (TM) to document the types of forest tracts and the changes occurring in them (Kilpeläinen and Tokola 1999; Roy et al. 1991). Some of the most common present-day satellites and sensors used for LULC mapping are listed in Table 15.1 (note that there are many other such sensors, with new ones being designed and launched regularly). However, due to periodic cloud cover and the coarser temporal resolution of many of these satellites, it was difficult to gather cloud-free images at the regional level for observing the changes that occurred in the forest type at short-term intervals. However, in the last few decades, many studies have used the NOAA Advanced Very High-Resolution Radiometer (AVHRR) data to map large-scale LULC attributes (Cihlar 2000; Hansen et al. 2000) and SPOT-4 Vegetation (Qi et al. 1993), which provides observations of the Earth on a daily basis. These kinds of works use the variations in the Normalized Difference Vegetation Index (NDVI) parameter to track phenological changes in seasonal forest or vegetation and the stresses on and the robustness of the foliage. However, to distinctly understand landscape dynamics at a regional scale and undertake detailed vegetation, monitoring multi-temporal data of less than 1 km spatial resolution is essential (Herold et al. 2008).

More recently, datasets and techniques like hyperspectral imagery and multiple imagery fusion have been developed, which have proved their efficiency to extract vegetation cover in a much better way. Vegetation extraction from hyperspectral imagery is now possibly researched more than its extraction from multispectral imagery. When comparing multispectral imagery having nearly 12 spectral bands with that of hyperspectral imagery, the latter clearly stands out with hundreds of spectral bands. For various vegetation studies, like that of reflectance or absorption of spectral signatures from individual species, hyperspectral sensors are better suited. Hyperspectral imagery is also better differentiated from complex mixed pixel communities (Mishra et al. 2015; Kuenzer et al. 2015a, b).

Table 15.1 Information about some of the common sensors presently used in vegetation mapping and their features

Sensors	Features	Vegetation mapping application
Landsat 4-5 TM	Spatial resolution – thermal infrared band = 120 m and multispectral bands = 30 m from Landsat 4 and 5 (1982 to present); swath – 185 sq.km; temporal resolution – 16 days	Mapping vegetation at community level
Landsat 7 ETM+ (Landsat 7)	Spatial resolution – Panchromatic band = 15 m, thermal infrared = 60 m, and multispectral bands = 30 m (1999 to present); swath – 185 sq.km; temporal resolution – 16 days	Mapping vegetation at community level or some dominant species can be possibly discriminated
Landsat 8 OLI	Similar to Landsat 7, with additional bands for cirrus and coastal	Mapping vegetation at community level
Sentinel series	10 m and 20 m resolution bands, with Sentinel-1 having SAR capability	Mapping vegetation at community level or some dominant species can be possibly discriminated
IRS Resourcesat series	LISS-III resolution of 23.5 m and LISS-IV MX resolution of 5.8 m are ideal for vegetation mapping	Mapping vegetation at community level or some dominant species can be possibly discriminated
IRS Cartosat series	High- to very-high-resolution data available (PAN and MX), up to 30 cm PAN data and 1.2 m MX data	Mapping vegetation at community level or some dominant species can be possibly discriminated
SPOT	Spatial resolution – range from 20 m down to 2.5 m and SPOT VGT with a coarse resolution of 1 km; swath – 60 sq.km (HRV/HRVIR/HRG) and 1000 or 2000 sq.km for VGT	Capable of mapping vegetation at community level, species level, or global or national level (from VGT)
IKONOS	Spatial resolution – 1 m panchromatic, 4 m multispectral bands; temporal resolution – 3 to 5 days (off Nadir); swath – 11 sq.km	Local- to regional-scale vegetation mapping at species or community level or can be used to validate other classification results
MODIS	Spatial resolution – 250 to 1000 m for both Terra (2000 to present) and Aqua satellite (2002 to present). Swath – 2330 km (cross track) and 10 km (along track at Nadir); temporal resolution: 1–2 days	Mapping at global, continental, or national scale. Suitable for mapping land cover types
AVHRR	Spatial resolution – 1 km GSD with multispectral data from the NOAA series satellites (1980 to present). Swath – 2400 × 6400 km	Global-, continental-, or national-scale mapping. Suitable for mapping land cover types
QuickBird	Spatial resolution – 2.4 to 0.6 m panchromatic and multispectral imagery from a constellation of spacecraft; swath – 16.5 sq.km; temporal resolution – 1 to 3.5 days depending upon the latitude	Local- to regional-scale vegetation mapping at species or community level or used to validate vegetation cover extracted from other images

(continued)

Table 15.1 (continued)

Sensors	Features	Vegetation mapping application
GeoEye series	High-resolution MX data for vegetation mapping	Mapping vegetation at community level or some dominant species can be possibly discriminated
WorldView constellation	One of the highest resolution datasets for vegetation mapping (PAN – 31 cm)	Mapping vegetation at community level or some dominant species can be possibly discriminated
ASTER	Spatial resolution: 15 to 90 m resolution images with 14 spectral bands from the Terra satellite (2000 to present)	Capable of regional- to national-scale vegetation mapping at species or community level
Hyperion	Spatial resolution – 30 m; hyperspectral image having 220 bands starting from visible to short wave infrared (2003 to present)	Mapping vegetation at regional or species level

AVIRIS is one of the finest examples of hyperspectral imagery. It provides calibrated images in nearly 224 spectral bands, covering the wavelength range from 400 to 2500 nm. Based on absorption by molecules and signature scattering by particles, the information present in those bands is being used for the identification, measurement, and monitoring of the constituents of the Earth's surface like vegetation types (Rounsevell et al. 2006). An example of a study done using AVIRIS imagery is from China and San Pablo Bay of California, USA, to classify salt marshes (Li et al. 2005). The final output was satisfactory, considering the fact that two main marsh vegetation species, *Spartina* and *Salicornia*, covered nearly 93.8% of the total marsh. In another similar work, Rosso et al. (2005) studied the structure of wetlands in California's San Francisco Bay to formulate a framework for their sustainable management. The results obtained from this study differentiated the five varieties of sugarcane, showing that hyperspectral imagery has the ability to differentiate two different plant species, which can otherwise be very difficult using multispectral images (Myneni et al. 1997a, b; Romshoo et al. 2002a, b).

In spite of the fact that the general procedures including pre-processing and classification needed for multispectral and hyperspectral images are quite the same, one of the challenges remains the processing of hyperspectral data. Specialized, cost-effective, and computationally efficient procedures are required to process hundreds of bands (Varshney and Arora 2004). To extract vegetation communities or species from hyperspectral imagery, a set of signature libraries of vegetation are usually required. In almost all of the cases in which ground data is used with hyperspectral data or captured through a spectrometer, the establishment of a spectral signature library is essential. However, vegetation libraries for particular vegetation communities or species may be available already for certain applications.

15.4 Vegetation Mapping Through Image Fusion

For a given application the information collected from the individual sensor may not be consistent or be imprecise and incomplete. For improving vegetation classification, image fusion of remotely sensed data with multiple spatial resolutions is considered as an effective technique. Efficiently combining remote sensing data with various spatial, temporal, and spectral resolutions with the help of image fusion is required for correctly mapping the vegetation. Many of the recent studies now focus on the creation of new fusion algorithms (Zhu and Tateishi 2006; Qiu et al. 2004). For instance, a frequency buffer model was proposed by Li et al. (2006) to remove the problem of merging panchromatic images of high frequency and multispectral images of low frequency. Another new temporal fusion classification model was developed by Zhu and Tateishi (2006), which is based on the statistical fusion of multi-temporal satellite images. Some of the frequently used algorithms for image fusion are Brovey transform, principal component transform, HSI, and smoothing filter-based intensity modulation, all of which improve the spatial resolution but also distort the original spectral signatures to a certain level (Dickinson and Henderson-Sellers 1988). An algorithm having enhanced color normalized was developed by Wu (2005) to combine the lower spatial resolution multispectral images with higher spatial resolution panchromatic images and to remove the color distortion that occurs with some existing techniques. Various image fusion methods were developed by Colditz et al. (2006) to understand the impact of the accuracy of land cover classification starting from common techniques like hue-saturation-value transform, Brovey, and principal component analysis to higher and complex approaches such as wavelet transformation, adaptive image fusion, and multi-sensory multi-resolution image fusion technique. Thus, image fusion has changed the earlier problem of low accuracy in vegetation cover mapping and is responsible for obtaining higher accuracy. Alongside image fusion, the advent of machine learning algorithms and object-based image classification methods and the different methods available in this regard have greatly facilitated LULC mapping and the extraction of vegetation patches and types from them (Akar and Gungor 2012; Guo et al. 2018; Htitiou et al. 2019; Vasilakos et al. 2020).

15.5 Approaches of Vegetation Mapping

Figure 15.2 depicts the types of datasets, indices, and models that have been used in vegetation mapping studies. As per the diagram, NDVI is the most adopted index by various researchers throughout the world. After NDVI, the second most utilized model was that of supervised classification using maximum likelihood. Apart from these two unsupervised classification and visual image interpretation were also being used in many studies. Most models like decision tree and redundancy analysis are also used but to a limited extent.

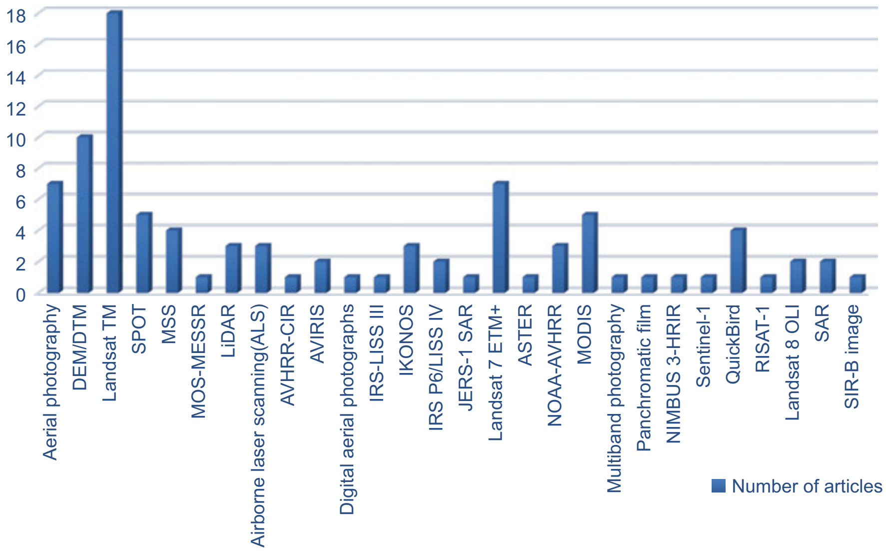

Fig. 15.2 Different types of remote sensing data/models used in various vegetation mapping studies

Figure 15.3 reveals that, among all types of satellite data, Landsat TM and ETM+ data have been the most widely utilized for mapping vegetation cover and biodiversity status as per the sampled literature. Landsat data, due to its free availability and medium to high spatial resolution, provides a wide range of opportunities to map and understand the spatiotemporal dynamics of different phenomena occurring on the Earth's surface. Digital elevation model (DEM) and digital terrain model (DTM) were used to extract the terrain characteristics. It is clear that most of the studies have used Landsat data due to its multi-temporal/multi-sensor and free availability characteristics and long duration of availability, followed by MODIS, QuickBird, and SPOT datasets. However, SAR, SIR-B image, NOAA-AVHRR, MOS-MESSR, and IKONOS have been least used for this purpose, probably because of their accessibility and procurement issues and technical familiarity.

15.5.1 Worldwide Distribution of the Sampled Studies on Vegetation Mapping

Figures 15.4 and 15.5 present a picture of the distribution of vegetation mapping studies across the world as discerned from the sampled studies. The maximum number of studies is concentrated in North America (especially in the USA and Canada), followed by Australia and Asia. Among all Asian countries, most of the studies concerning vegetation cover and biodiversity status have been carried out in India and China. At the country level, most studies have been carried out in the USA,

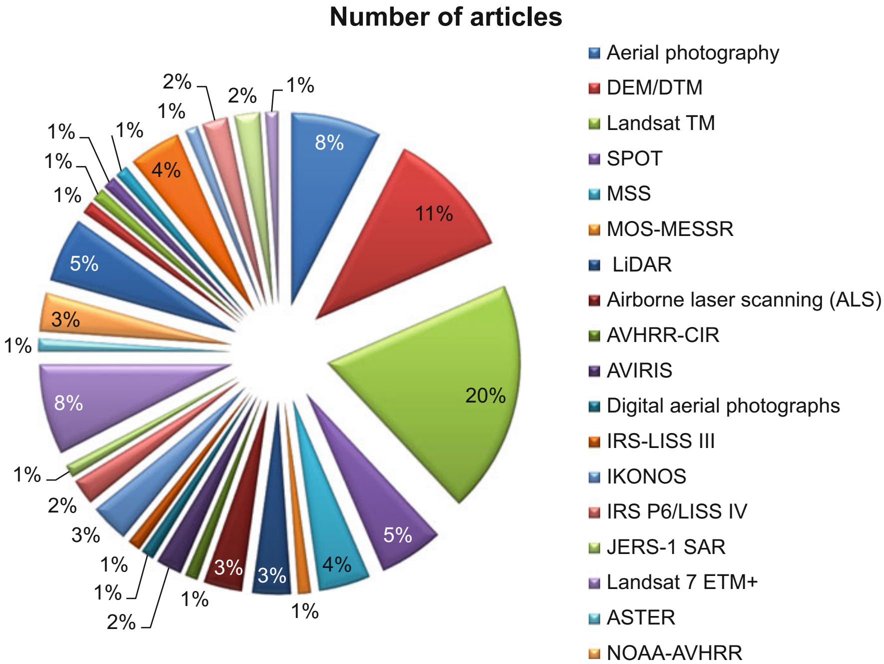

Fig. 15.3 The pie chart depicts the remote sensing data used in various studies related to vegetation mapping

while these are considerably lower in countries like Spain, Sudan, Namibia, Mongolia, and Mexico.

Remote sensing-based studies on vegetation mapping and biodiversity status have a long history, commencing from the 1970s, with the availability of Landsat-1 data, which was launched in 1972. During the initial period of 28 years, i.e., 1977–2005, there were a comparatively lesser number of studies in the sampled dataset, which together account for 23% of the total sample (Fig. 15.6). The above chart depicts the distribution of vegetation mapping studies in different time periods, and it is notable how the science of vegetation mapping has evolved over time. From the chart presented above, it can be concluded that from 2005 onward, the number of studies (75% of the total number) based on vegetation mapping has continuously increased and more and more new advancements have been made in the field of vegetation mapping, with better and higher resolution sensors, more data availability from a larger constellation of satellites, and better computational methods to analyze the same. The importance of this field thus becomes apparent. It is also clear that most studies have been carried out from 2010 onward, especially due to methodological and technological advancements.

Figure 15.7 shows the distribution of articles published in different countries since 1970 up to the 8th of July 2021, when this study was initiated. The map depicts that the USA contributed the maximum number of published articles, with a total of

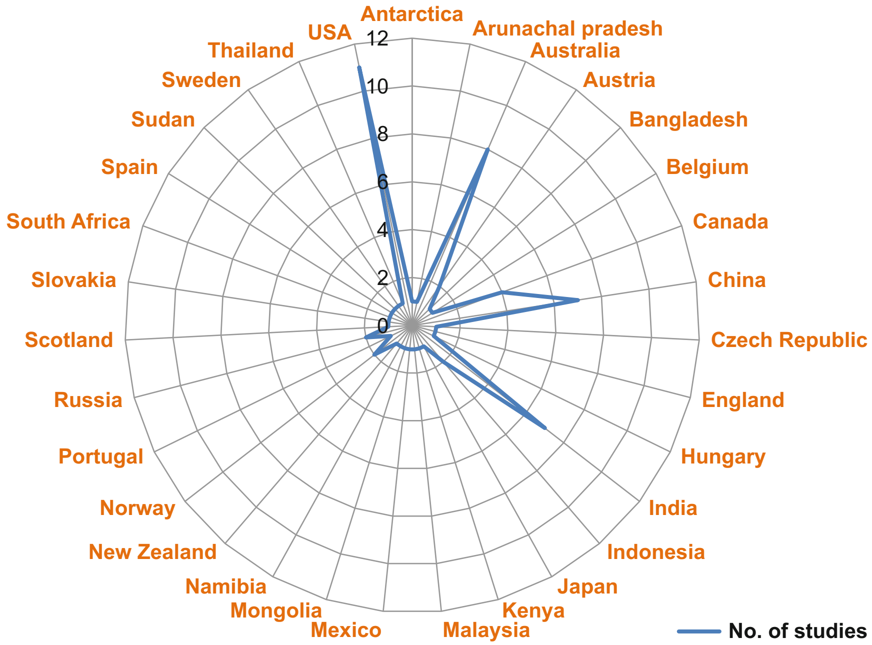

Fig. 15.4 Country-wise distribution of the sampled vegetation mapping studies

1574 papers in the sampled dataset related to "Vegetation Mapping using Remote sensing," followed by China (836), Canada (340), Germany (340), India (325), Australia (297), UK (296), France (283), Italy (273), Brazil (240), Spain (205), the Netherlands (178), Japan (125), South Africa (119), Belgium (110), Iran (96), Russian Federation (94), Finland (74), Switzerland (74), and Malaysia (68). The rest of the countries have relatively lagged behind with far fewer number of articles in this theme.

The bar graph presented in Fig. 15.8 shows the top 20 journals and their number of published articles in the above theme since 1970 till July 8, 2021. The *International Journal of Remote Sensing* published the highest number of articles with a total number of papers of 540 on "Vegetation Mapping using Remote sensing." The other top journals publishing articles in this theme were *Remote Sensing of Environment* (511), *Remote Sensing* (396), *IEEE Transactions on Geoscience and Remote Sensing* (141), *ISPRS Journal of Photogrammetry and Remote Sensing* (124), and so on. Among the sampled journals, *Shengtai Xuebao/Acta Ecologica Sinica* published the least number of papers in this domain (30 articles).

(Source: Scopus Database, https://www.scopus.com)

(Source: Scopus Database, https://www.scopus.com)

The line graph in Fig. 15.9 presents the total documents published per year since 1970 up to July 8, 2021. Publications commenced since 1970 (the start of the study period) and increased in almost every subsequent year. So far, the maximum articles

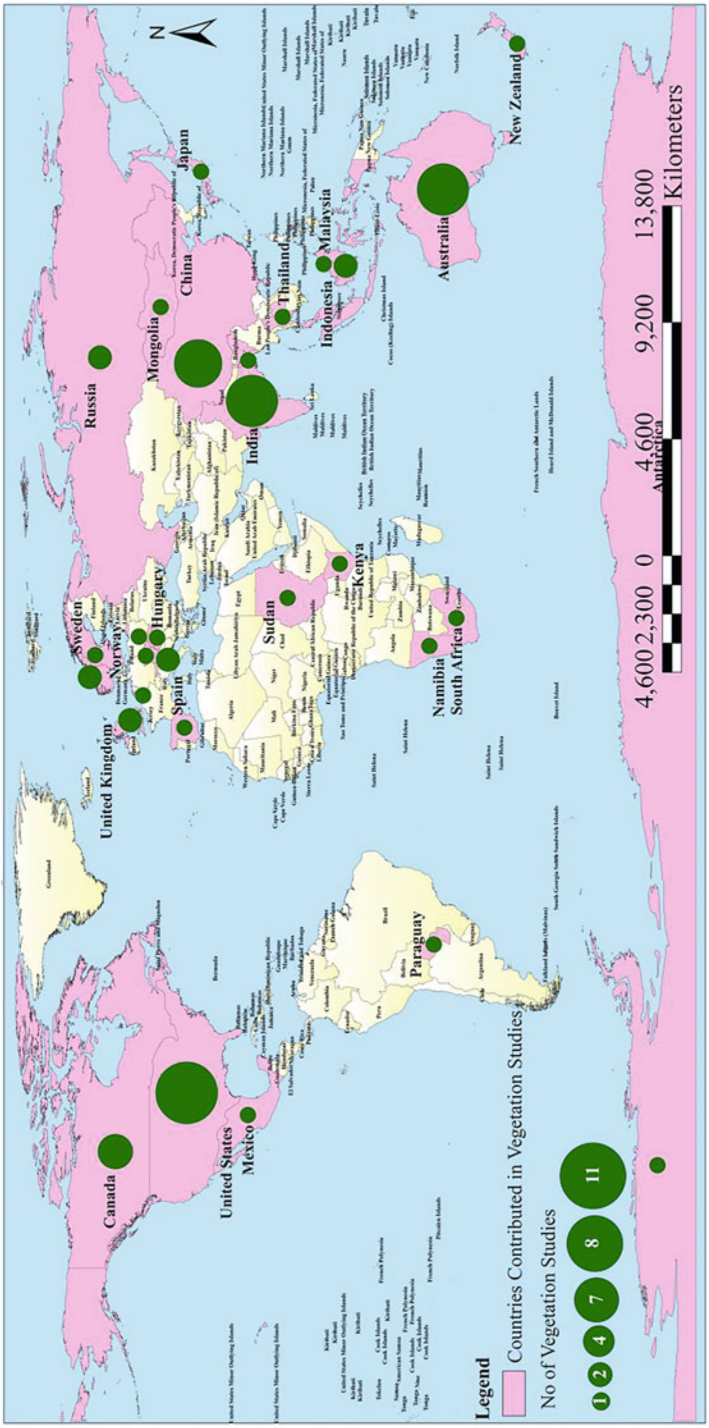

Fig. 15.5 Country-wise distribution of the sampled vegetation mapping studies

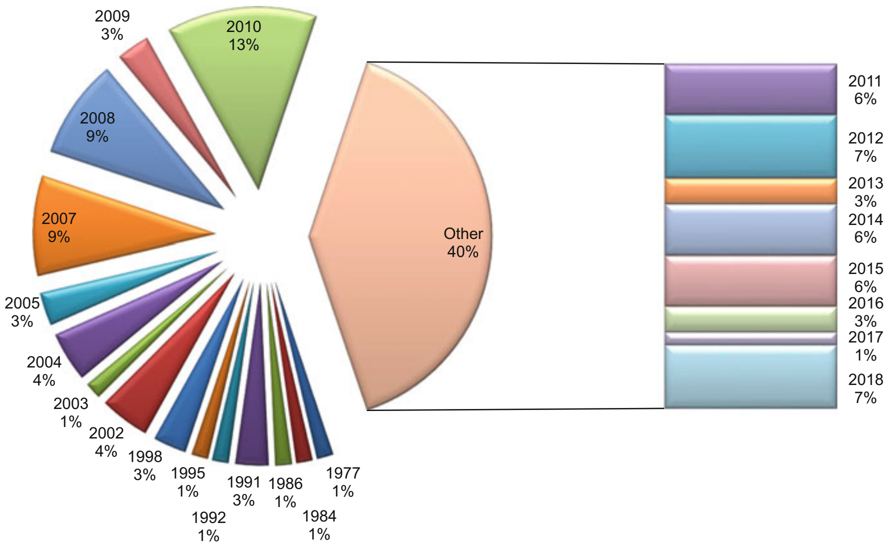

Fig. 15.6 Number of articles published regarding vegetation mapping in different time periods

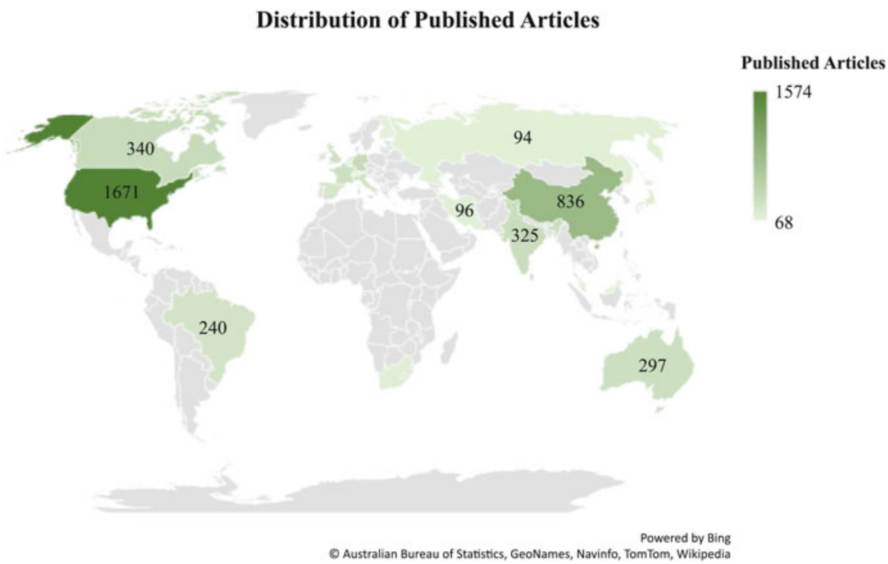

Fig. 15.7 Top 20 countries with their numbers of articles (Source: Scopus Database, https://www.scopus.com)

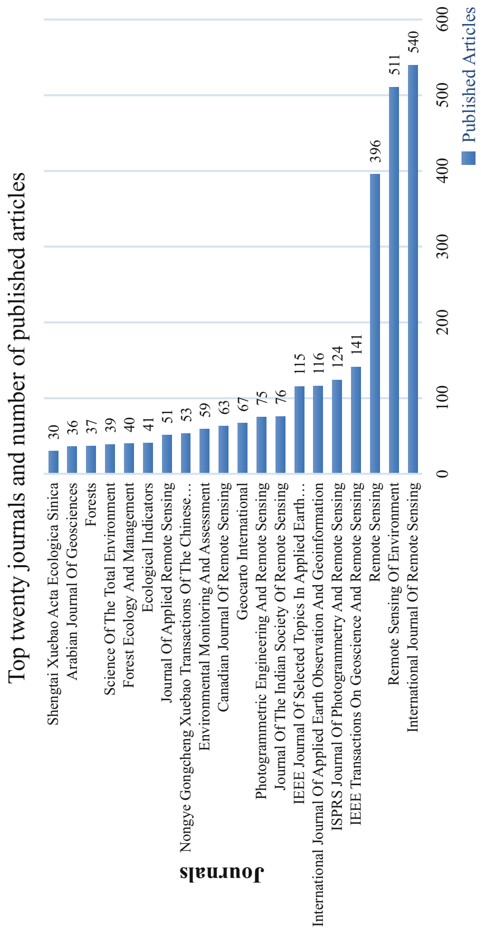

Fig. 15.8 Scopus-indexed journals and number of articles on vegetation mapping using remote sensing

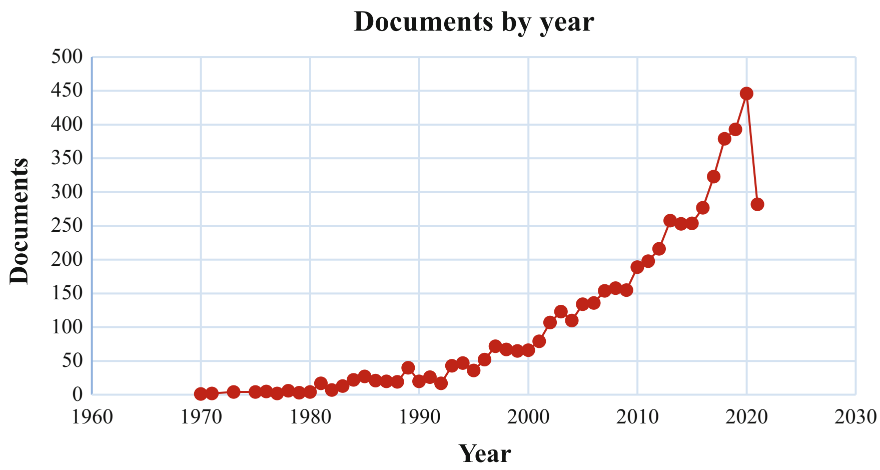

Fig. 15.9 Documents on vegetation mapping using remote sensing from 1970 to July 8, 2021

on this theme have been published in 2020, while the data for 2021 is only up to July 8 of that year and so shows a lower number. From this graph it might be said that the importance of this theme (Vegetation Mapping using Remote sensing) has increased continually among the research community and the trend shows that it will remain a vital avenue of research, as more and more sustainable living frameworks are sought to overcome the effects of climate change and land transformations.

(Source: Scopus database, Author keywords co-occurrence with overlay visualization)

Figure 15.10 was created with the help of VOSviewer software, wherein the total recorded author keywords was 11,929. The minimum number of occurrence of keywords was selected as 5 with a threshold level of 1301. The final selection of keywords was 1000 in number. The most used and recognizable keyword was “remote sensing,” with 1697 occurrences and 24,247 of total link strength. The other used keywords were vegetation, mapping, satellite imagery, forestry, vegetation mapping, Landsat, satellite data, NDVI, decision trees, normalized difference vegetation index, accuracy assessment, land use, ecosystems, mapping method, land cover, China, biodiversity, USA, vegetation cover, vegetation index, climate change, and so on. The color of the keywords indicates the average publication year. The recent and emerging keywords are machine learning, Sentinel, Sentinel-1, Sentinel-2, Sentinel-2a, topography, overall accuracies, principal component analysis, logistic regression, linear regression, support vector regression, predictive analytics, Pakistan, temporal analysis, spatial resolution, remote sensing images, spatial and temporal variation, rivers, field method, fire hazards, random forest modeling, spectral vegetation indices, random forest classification, high-resolution imagery, and so on, which are represented in shades of yellow. This analysis will be helpful for those researchers interested in discerning the frontiers of research at present in

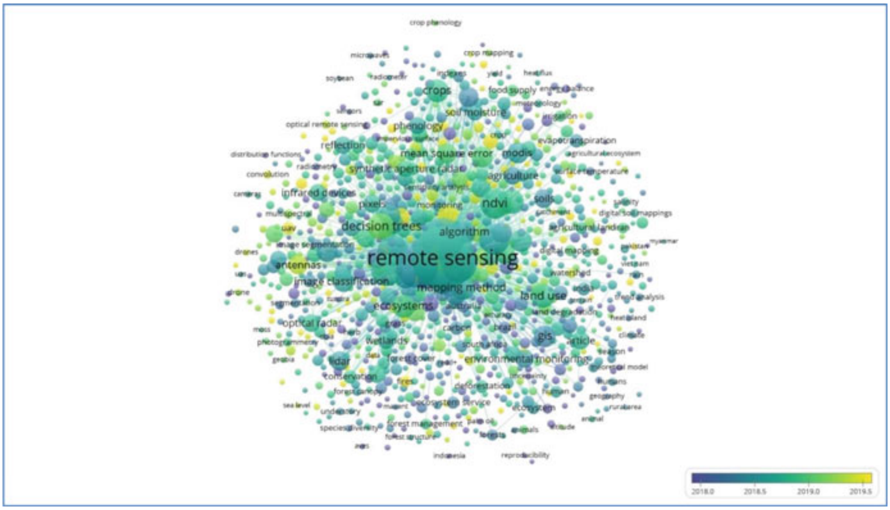

Fig. 15.10 Bibliometric map of author keyword co-occurrence with overlay visualization mode

this domain as this overlay bibliometric map shows the temporal dynamics of this research.

(Source: Scopus Database co-authorship countries with overlay visualization)

Figure 15.11 was created with a total of 206 countries (by default), wherein the minimum number of documents was selected as 5 with thresholds meeting value as 67. The final selection of total countries was 67. Thicker lines and close proximities indicate a stronger relationship between two countries. The output of this map displayed that the USA ranked top with a total of 399 links with other countries, followed by China (301 links), Germany (198 links), UK (190 links), France (143 links), Italy (143 links), the Netherlands (132 (links), Canada (125 links), Australia (121 links), Spain (99 links), Belgium (91 links), Iran (83 links), Japan (80 links), India (77 links), Brazil (76 links), and so on. The blue color shade indicates the average year when research in this field started in a country (as per the final sample of articles and not in the actual timeline of research therein). Studies began in the USA from 2018.2, while other countries (including China, India, Japan, Germany, and the UK) reported values between 2018.8 and 2019.2. The emerging countries are Bangladesh, Poland, Iraq, Bulgaria, Pakistan, Saudi Arabia, Turkey, Morocco, Croatia, Ethiopia, and others, as indicated by yellow tones (which indicates a more recent time period of commencement of research in a country in this domain, again, only according to the selected articles and not the actual such timeline), with an average year of 2019.4 for their published works.

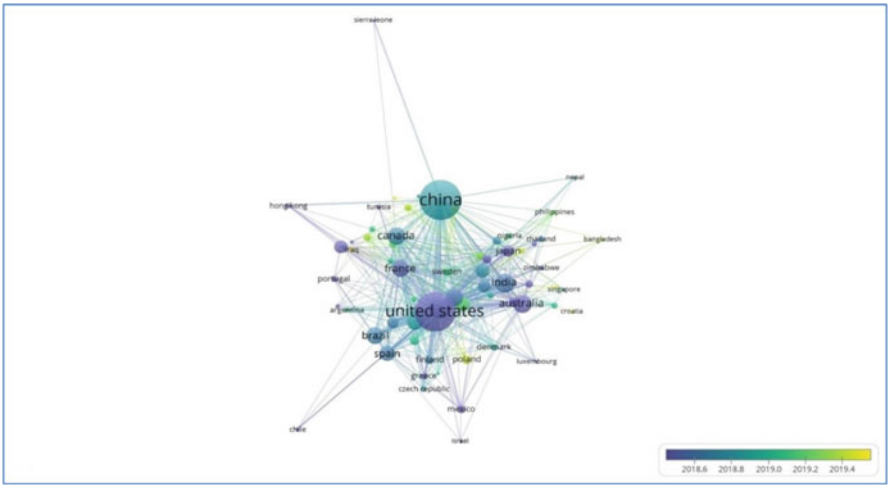

Fig. 15.11 Bibliometric map shows the co-authorship countries with overlay visualization mode. Yellow color shows the countries recently working on vegetation mapping research using remote sensing

15.6 Conclusion

The present study reviewed various aspects, methods, and approaches of mapping vegetation cover and tracked its evolution from using traditional geospatial technologies to using modern models like decision tree and redundancy analysis. The study thus examined in detail the assessment reports and research papers for the methods, models, and techniques used for mapping vegetation throughout the world. This study has given an overview of the emerging trends and gaps in the existing research on vegetation mapping with related challenges for future research. We examined how vegetation mapping as a concept and tool has been conceptualized and operationalized by applying a systematic review protocol to a set of 70 peer-reviewed case studies, which provide a quantitative and qualitative analysis of the key trends and research paths that emerged. We found that while gaining momentum, the vegetation mapping concept has increasingly attracted case study-based research from different parts of the world and is being used as an evolving tool for better conservation of the landscape.

As a result of our analysis, we want to highlight the following recommendations for further research:

- In the upcoming studies related to vegetation mapping, more high-resolution images can be incorporated where possible so as to enhance the outputs derived.
- Also, more high-end models like decision tree, redundancy analysis, and other machine learning algorithms can be utilized to increase the output accuracy.

- The contextual coverage of the research field should increase to provide more robust knowledge generation of how the concept can be useful for landscape conservation planning and sustainable land use management.

This exercise presents an insight into the different methods, models, and data types used for vegetation mapping to enhance the objectives of the project in hand. The findings revealed that vegetation mapping studies were analyzed primarily via case studies and technical reports. The review has revealed that discrepancies in methods and approaches do crop up in different regions according to changes in the scope of the studies. Advancements in geospatial techniques, particularly in remote sensing data, GIS, and three-dimensional modeling techniques, have revolutionized vegetation mapping. This study recommends that managing identified areas for which detailed collection of primary LULC data through well-planned field surveys is done should be performed to correlate the same with the satellite-derived datasets for better classification accuracy and framing of algorithms. Thus, a multi-dimensional approach working toward a shared vision, based on stakeholder engagement for detailed and repeated LULC mapping at the landscape level, is suggested.

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Chapter 16
Application of Participatory Rural Appraisal and Geospatial Techniques for Analysing the Dynamics of Mangrove Forest and Dependent Livelihood in Indian Sundarban

Biraj Kanti Mondal and Ashis Kumar Paul

Abstract The current effort intended by the application of participatory rural appraisal (PRA) and geospatial technique is to inspect the dynamics of mangroves, land use, land cover, and adaptation challenges with respect to adverse environmental situations pertaining to Indian Sundarban. In the milieu of high dependency on primary economic activities, about 4.4 million inhabitants of Indian Sundarban are facing continuous, enormous difficulties and challenges to adapt diverse events. Hence, an in-depth analysis of the diverse aspects of PRA and geospatial techniques in order to recognize the changes of mangroves, cause-effect rapport to the adaptability and challenges of the forest-dependent livelihood, and allied marginalized population of Indian Sundarban as a whole and the Gosaba block, in particular, has been designed. After preparing the pedestal exertion by using geoinformatics, some of the major PRA methods were employed in the study area following primary survey by two stage purposive random sampling method, and the data were reaffirmed through the direct interview and discussion with households and individuals. The study reveals that diverse etiquettes of climate change, increasing the economic stress by reducing the agricultural and fishing productivity, reducing their variety, increasing their forest dependency, and mounting the uncertainty, and consequently their socio-economic conditions became more vulnerable. The study provides useful insights into the realities of livelihood, activities, and mangrove forest dependency which could be incredibly constructive for conserving the forest as well as policy framing, strengthening the involvement of local people.

Keywords PRA · Geospatial · Sundarban · Mangrove forest · Conservation · Management · Vulnerability

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16.1 Introduction

Sundarban Biosphere Reserve (SBR) is the largest active coastal delta having unique physical, ecological, and climatic features, contoured by numerous rivers, complex network of tidal waterways, mudflats, and largest mangrove forest ecosystem. It is the largest mangrove ecosystem and known for its uniqueness, and it has been considered as a land of natural resources with physical toughness, and the livelihood has always been attached largely with primary economic activities, like agriculture, fishing, forest product collection, etc., without profound notion of industrial improvement. In Sundarban, rapidly increasing population creates more demand of economic growth, and as it was absent in most of the blocks, people are trying to exploit the physical resource base and collect forest product; thus the mangroves are under pressure. The unfavourable situations like these and the lack of integrated planning and management system for the resource base with active participation of people head towards ecological imbalances and result in high degree of environmental degradation. Therefore, considering the demand and furnish circumstances to address the economic and environmental needs, no one can refute the call for people's participation in forest management in Sundarban. Thus to inculcate the participatory forest management, PRA technique is very useful in maintaining, developing, managing, and protecting the mangrove forest in Sundarban, and there is no space for a second opinion.

The salt-tolerant mangrove species generally grow in the intertidal zones, and they found their suitable stay in the active coastal delta of Ganga-Brahmaputra-Meghna confluence and form the world's largest mangrove habitat which is known as the UNESCO's 'World Heritage Site' for its uniqueness (Laha 2019; Sahana and Sajjad 2019). The mangrove species are declining continuously at diverse rates due to enormous reasons. As the people associated with the mangrove forest are largely dependent on the physical resources in the area, they are very much inclined to use, often overuse, and extract product using such mangrove species like non-timber forest products and honey collection. Thus, man by their various activities hampers the mangrove species and their artificial plantation, progression, and reproduction; thus it has been essential to involve the local community in the development process for the restoration and conservation of mangrove species and management of forest cover by suitable propagation technique, and there is the role of execution of PRA methods. The inhabitants must be aware of the fact that by preserving the mangroves and conserving the biodiversity, we can maintain the ecological bridge between the terrestrial and aquatic bionetwork, which is essential for sustainable development of Sundarban and the livelihood of the local people as well.

SBR has been victimized by diverse etiquettes of climate change due to which the enormous inhabiting population displaces, increasing economic stress and environmental degradation due to climate change, and related issues are acting as the diverse force that poses a challenge to the human development and re-establishment of mangroves (Chowdhury et al. 2008; Mukhopadhyay 2009; Datta et al. 2011; Jahan 2018; Laha 2019; Sahana and Sajjad 2019; Sahana et al. 2019a, b). As the Sundarban region is geophysically and ecologically susceptible (Bakshi and Panigrahi 2015; Mondal 2018; Sahana et al. 2020a) and often devastated by super cyclones and floods (Sahana et al. 2020a, b; Ghosh and Mukhopadhyay 2016), what is even more alarming is the fact that as a consequence of these hazards and climate change, this area is facing tremendous pressure due to sea level rise that is culminating into loss of habitat and cultivable land, compelling people to dislocate. The occurrence of various climate change events and effects on various segments including the mangroves was accumulating in various literatures (Hazra et al. 2002; Mitra et al. 2009; WWF 2010; Nandy and Bandyopadhyay 2011; Banerjee 2013; Raha 2014; Chakraborty 2015; Pramanik 2015; Kusche et al. 2016; Trivedi et al. 2016; Sahana et al. 2016; Nandargi and Barman 2018; World Bank 2014, Rehman et al. 2021).

Some studies emphasized on the linkages between climate change and livelihood aspects, like crop yield and migration in other geographical region and in dissimilar context (Thirtle et al. 2001; Frich et al. 2002; Brooks 2003; Feng et al. 2010; Pachauri 2008a, b; Hahn et al. 2009; Gornall et al. 2010; Marchiori et al. 2012; Iqbal and Roy 2014; Ahsan and Warner 2014; Kumar and Viswanathan 2015; Dumenu and Obeng 2016; Pound et al. 2018a, b), but there is very limited research on Sundarban area in the theme. The existing works strengthen the occurrence of climate change in Sundarban and envisaged that climate change has negatively influenced the agricultural productivity and allied livelihood issues. Some of the earlier studies analysed the mangrove conservation, climate change, and livelihood assessment (Danda 2007, 2010; Ghosh 2012; Mandal et al. 2011; Mistri 2013; Mondal 2015; Debnath 2013a, b; Halder and Debnath 2014; Ghosh et al. 2015, 2018 Ghosh 2018; Danda 2019; Ambast et al. 1998; Hazra et al. 2002; World Bank 2014; Raha et al. 2012; Mahadevia and Vikas 2012; Hijioka et al. 2014; Chakraborty 2015; Pramanik 2015; Sahana et al. 2016; Trivedi et al. 2016; Sahana et al. 2020a, b; Kumar et al. 2007; Hertel and Rosch 2010; Chand et al. 2012; Mandal and Mandal 2012; Jana et al. 2012; Mondal 2012; Debnath 2018; Hazra et al. 2014; Hajra et al. 2017; Pound et al. 2018a, b; Hajra et al. 2017; Roy and Guha 2017), but there is very limited research on PRA technique in Sundarban.

The islanders of Sundarban constantly have to tolerate both detectable and not-so-visible uncertainties to uphold their livelihood, especially associated with primary and forest-based activities, and therefore they are often bound to try alternative way of income generation even working in a turbulent situation. The inhabitants of Sundarban often live in edge as the climatic hazards and related effects like sea level rise, breaking of earthen embankments, inundation of households and agricultural lands, and salinity incursion in land and water always fall them more uncertainties. Moreover, significant reduction of agricultural land and its production, lessening of fish-catch make them economically more vulnerable and due to such economic instability and food crisis upshot migration of men and emerging of women-headed households. Thus the anecdote of inhabitants has always been a sad one, and their livelihood faces troubles starting from their journey of life in diverse aspect, and they have constantly been coping up with every vulnerable situation and trying to adapt. Hence, along with the application of PRA and geospatial techniques, the livelihood section was assessed in the context of risk and vulnerability due to changing climate-related issues as the pillar of the current study. The present effort is designed to assess the adaptations and challenges and standing of people associated with primary activities in the mangrove forest in vulnerable situations in a fragile Gosaba block of Sundarban. It would have been a great expose if the PRA methods are employed in all the other blocks of Sundarban. Henceforth, this submission seeks to delve deep into the questions of climate change-induced hazards, vulnerability, adaptation, and livelihood with a serious emphasis on mangrove management issues. With sincere attempt to tease out data from field surveys, interviews, and minute observation on the main along with secondary data sources and application of geospatial techniques and participatory rural appraisal techniques, this submission endeavours to tease out posers in the area of mangrove forest conservation, management, and livelihood in Sundarban.

16.2 Study Area

The current study concentrated on Indian Sundarban, which is distributed across North and South 24 Parganas districts of West Bengal (Fig. 16.1). This active coastal delta has a significant amount of mangrove forests and is known as World Heritage Site (1987) and Ramsar Site (2019). The area extends from 21°00′ North to 22°30′ North and 88°00′ East to 88°29′ East latitude and longitude, respectively.

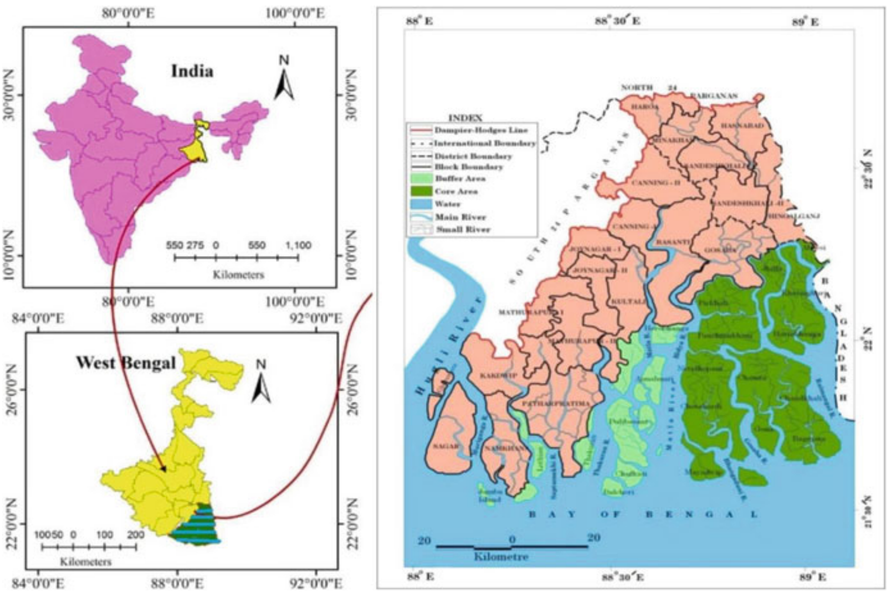


Fig. 16.1 Location map of Indian Sundarban

The Indian Sundarban Delta (ISD) is contoured by numerous rivers and complex network of tidal waterways, mudflats, and mangrove forest, and the northern interface of the region is demarcated by the Dampier-Hodges line (Das 2006). According to the Census of India (2011), about 4.4 million people (at present close to five million) are dwelling in the Sundarban. The area comprises 19 blocks: 6 blocks of North 24 Parganas and 13 blocks of South 24 Parganas districts of West Bengal. About 4493.60 sq.km. inhabited landmass of Indian Sundarban is scattered over 54 islands out of a total of 120 islands.

16.3 Database and Methodology

The current attempt followed a three-step methodology with a fusion of primary and secondary data. The primary data was collected through primary survey and field visit and observation; during that, direct interview and discussion with households and individuals were conducted following two stage cluster purposive random sampling method. At the first stage, three villages (for micro level investigation) were chosen randomly from dissimilar Gram Panchayats positioned in diverse island of Gosaba block, while in the second stage, households within these villages were selected randomly for the survey. Direct interview (preferably associated with primary activities) was carried out during the survey, choosing 50 households from each village covering a total of 150 households in the year 2018–2019. The questionnaire scheduled was designed by the questions about occupation, major economic engagement, agricultural land, family member, land use change, etc. Some other questions were asked concerning the nature of climate change and its consequences like losses of agricultural land, saline water intrusion, reduction of agricultural production, embankment collapse, reduction of the mangroves, diverse PRA methods, alternate income opportunities, level of impact on life and livelihood, temperament of vulnerability, and adaptation strategies and challenges, whereas the secondary data has been collected from Census of India, District Statistical Handbook (DSH 2009), District Human Development Report (DHDR 2009), Report of State Disaster Management Authority, and published reports/literatures. To observe the forest cover dynamics, land use land cover (LULC) classification of Sundarban has been protracted by retrieving the satellite images from USGS of 1975 (Landsat1 MSS) and 2014 (Landsat 8 OLI data) and Gosaba block of 2020 (Landsat 8 OLI data) by using ArcGIS 10 and ERDAS IMAGINE 9.2 software. In due course, to analyse all the data, statistical techniques, quantitative methods, and GIS mapping were carried out using geoinformatics as a key tool. The methodological steps followed here are as follows: at the *pre-field stage*, various literatures and reports were reassessed, and in the *field stage*, primary data was collected through proper questionnaire survey along with the minute observations, and in conclusion, i.e. *post-field stage*, the preparation of maps and graphs was carried out by analysing the data, and eventually the description was geared up.

16.4 Results

16.4.1 Impact of Climate Change on Sundarban Biosphere Reserve (SBR)

As the Sundarban is a physically feeble region where most of the inhabiting people depend on natural resource, especially on mangrove forest and primary activities like agriculture and fishing, any sort of catastrophic events, hazards, and climate change gets deeply rooted in the region, and it enhances the vulnerability, which increases poverty and inequality in various socio-economic sectors (Dhara and Paul 2016). On the other hand, poverty and deprivation throw challenge in the way of disaster preparedness often exacerbating the humanitarian crisis. In this backdrop, it is therefore crucial to understand how the issues of climate change-induced hazards amplify vulnerability, diminish the capacity in agriculture, and increase uncertainty by reducing mangrove and adaptability. The vulnerability constituent to climate change makes people more prone to risk, and thereafter their capacity in response to vulnerable situation was judged. The climate-induced physical vulnerability boosts up demographic and socio-economic vulnerability and makes people more sensitive, makes them more exposed to risk, and reduces their adaptive capacity which was judged from micro level investigation in Gosaba block. The issues and threats of climate change that are pertaining to Sundarban which affect the environment and the livelihood of the associated people are tabulated below (Table 16.1).

Therefore, the diverse nature of threats due to climate change and its connection with livelihood and other strongly impacted issues is tabulated which is self-explanatory (Table 16.2).

16.4.2 Climate Change and Vulnerability of Sundarban

In Sundarban, climate change and extreme weather events, like attack of severe cyclone etc. is integrally related (Pachauri 2008a, b) to the increasing risk and vulnerability and resulting agricultural loss and ultimately be happening backwardness and poor socio-economic conditions of the already marginalized group. The area which is close to the forest is more vulnerable and risk prone due to embankment collapse and damages, especially during a hazardous situation (Hazra et al. 2002; Chakraborty 2015; Samling et al. 2015; Sarkar et al. 2016; Ghosh 2017; Bandyopadhyay 2018; Karmakar and Roy 2019; Mukherjee et al. 2019; Rehman et al. 2021). To understand the impact, especially the belongings of climate change on sea level rise, embankment damage, storm surge and coastal flooding, and saline inundation, the risk zonation map has been prepared. The map (Fig. 16.2) reveals that most of the coastal and fringing blocks belong to the very high-risk zones, starting from the Sagar to Hingalganj block, while Patharpratima, Namkhana,

Table 16.1 Consequences of climate change in Sundarban

Climate change	Facts	Impact/vulnerability	Facts
Temperature	Increased 0.5°C	*River flow*	Changing
Rainfall amount	Decreases	*Riverbank erosion*	Increased
Cyclone intensity	Increased	*Flood hazard*	Increased
Super cyclone	Greater than before	*Embankment damaged*	Increased
Overall weather	Changed	*Soil erosion*	Increased
Frequency of cyclone	Increased	*Saline water inclusion*	Increased
Intensity of cyclone	Changed	*Salinity of soil*	Increased
Damages by cyclone	Increased	*Deforestation*	Increased
Rainy days	Fewer	*Mangrove forest*	Decreased
Rainy season	Shorter	*Agricultural area*	Decreased
Winter season	Late coming and warmer	*Inundation of land*	Increased
Summer season	Coming early and longer	*Land degradation*	Increased
Sea level rise	Increased	*Agricultural potentialities*	Decreased
Fresh water	Less availability	*Crop production*	Decreased
Ecosystem services	Diminishes	*Fish production*	Decreased
Surface water	Decreased	*Honey collection*	Decreased
Ground water	Decreased	*Damages of house*	Damaged
Coastal areas	Destroyed	*Inhabitants*	Displaced

Data source: Tabulated by the author (based on literature review: Pramanik 2015; Ghosh 2018; Nandy and Bandyopadhyay 2011; Danda 2010; Hazra et al. 2014; WWF 2010; Nandargi and Barman 2018)

Kakdwip, Mathurapur II, Kultali, Gosaba, Minakhan, and Sandeshkhali blocks declining towards high-risk zone and the residual parts fit into the moderate risk zone.

The climatic vulnerability of the Sundarban region has been extremely high due to the severe attack of various cyclones for decades. Most of the coastal blocks are at high-risk zone in terms of cyclones, and therefore, natural calamities become a part and parcel of the livelihood of the inhabitants, especially the larger community who are depending on agriculture, and other primary economic activities are becoming worst affected. Occurrence of a cyclone, flood, sea level rise, riverbank erosion, and storm surge are the diverse issues which have a strong connection and impact like the destruction of coastal areas, reduction in income potentialities, inundation of land by saline water, embankment damage, and diminishing ecosystem services, mass displacement, and relocation of people (Hajra and Ghosh 2016; Hajra et al. 2016). An increase in frequency and the intensity of cyclonic event attacks in Sundarban were noticed since 1851 (Table 16.3) to estimate how much the inhabitants have to cope up with these calamitous circumstances.

It is evident that the increasing frequency, intensity of cyclonic events (Fig. 16.3) and related hazards mostly due to climate change damages the embankments, loss of cropping lands, mangroves and biodiversity rendered the region more susceptible. Thus, such recurrent damage to property increasing the helplessness of the people

Table 16.2 Threats and impacts of climate change in Sundarban

Threats	Nature	Strong impact	Connections with livelihood
Increasing sea surface temperature	0.019 C/year 0.06 C/decade	Aquatic life, mangrove ecosystem	Reduction of fish catches, overdependency on agriculture, creating extra pressure
Sea level rise (SLR)	Annual mean SLR:3.14 mm/ year Double/25 years	Mangroves, restrict plant regeneration	Inundation of agricultural land from flooding saline water, saline water stagnation, reduction of reclaimed land for agriculture, flood, etc. which reduces crop production
Cyclones	Increased intensity and frequency	Life, livelihood, resources	Crop damage, damages of vegetables; flooding, storm surges inundate lands
Land degradation	Land erosion 162 sq. km/ 30 years Land accretion: 82 sq.km/30 years	Reduction of mangrove swamps, mudflat and land area, coastal erosion; people are homeless	Land erosion and mangrove loss making people more inclined to agriculture; reduction of land holdings, fragmentations of lands, increasing fallow land, declining soil fertility
Rise in salinity	High tide, cyclone, storm surge, water stagnation, salinization	Soil, agriculture	Reduction of cropping variety, lessening productivity, increasing fallow land, increasing soil erosion, contamination of soil, affect ground water
Change in agricultural pattern	Shrunk 2150 to 1691 sq.km/2002 to 2009	Rain-fed agricultural lands, low intensity of cropping, reducing crop and paddy variety	Reduction of quantity and quality of crop production, changes in irrigation, increasing the use of fertilizers, insecticides
Deforestation	5% forest cover lost/ 1989 to 2009	Ecological, forest, man-animal conflicts	Affecting food production, soil erosion, fewer crop, tendency of flooding
Pollution	Heavy siltation and disposal of solid waste	Fresh water, tidal flow, sedimentation	Increasing crop diseases, reduction of crop growth and yield

Remarks: Increased poverty, encroachment of population, overexploitation of forest product, increase in salinity, spread of disease, increase man-animal conflict, lack of effective disaster management

Data source: Tabulated by the author based on the West Bengal State Action Plan on Climate Change; Centre for Science and Environment; Danda 2019; Hazra et al. 2014; Mondal 2018; WWF 2010

associated with agriculture and its aftermath has produced more poverty-ridden people as there are very limited alternative income opportunities.

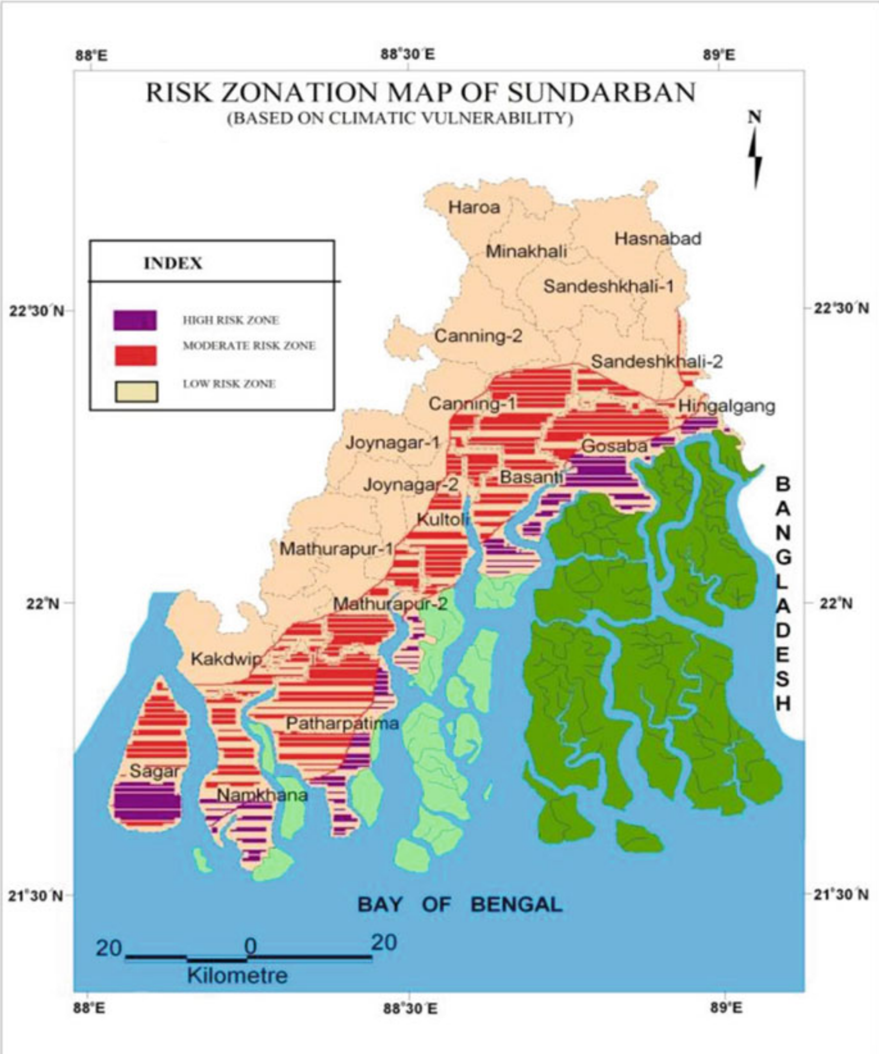


Fig. 16.2 Risk zonation map of Sundarban

Table 16.3 Natural calamities on Sundarban

Year	Before 1700	1701–1750	1751–1800	1801–1850	1851–1900	1901–1950	1951–2000	After 2000
Frequency	1	4	3	13	49	36	20	15

Source: State Disaster Management Authority, 2019

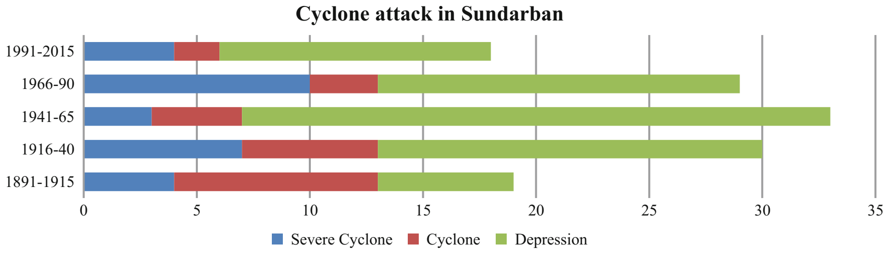


Fig. 16.3 Tropical cyclones land falling in the Sundarban. (*Depression*, a storm with an average wind speed of 31–61 km/h; *cyclonic storm*, 62–88 km/h; *severe cyclonic storm*, >89 km/h) Data source: http://www.rmcchennaieatlas.tn.nic.in

Table 16.4 Land utilization in different parts of Sundarban (1941)

Region	Cultivated area (%)	Culturable but not cultivated (%)	Unculturable (%)	Average acreage per holding
Northern plains of Sundarban	66	12	22	2.94
Reclaimed Sundarban	61	16	21	4.21

Source: Selected works of Prof. S. P. Chatterjee, Vol.-I, 2004, Pub. by NATMO

16.4.3 Land Use and Land Cover Dynamics of Sundarban

The land use and livelihood pattern of the undivided part of the Sundarban of Bengal was quite strange to catch attention. According to the 1941 data, mentioned below (Table 16.4), the major areas of Sundarban can be divided into two regions, namely, northern plains of Sundarban and the reclaimed Sundarban (as by Prof. S.P. Chatterjee) (Chatterjee et al. 2004). The northern plains were ahead in terms of cultivation as it had a greater percentage of areas (66%) than the reclaimed Sundarban. But the culturable land, but not cultivated, and the average acreage per holding had greater values in the reclaimed Sundarban than the northern plains. The unculturable area was almost the same in both northern plains and the reclaimed Sundarban.

The climate -change has also strong impact on the land use and land cover of Sundarban which is directly related to agricultural practices and its adapting behaviour. Henceforth, -LULC classification of the entire Sundarban has been protracted by retrieving the satellite images from USGS of 1975 (Landsat1 MSS) and 2014 (Landsat 8 OLI) data by using ArcGIS and ERDAS IMAGINE -software. The study revealed that agriculture land decreases from 1195 sq.km. to 875 sq.km., i.e. from 1975 to 2014, whereas the vegetation cover also decreased but comparatively in a slower rate (Fig. 16.4). Both of these are decreasing as the settlement area is occupying the space at a faster rate and aggravating the landscape very rapidly as it was enlarged to 1159 sq.km. in 2014 from 912 sq.km. in 1975.

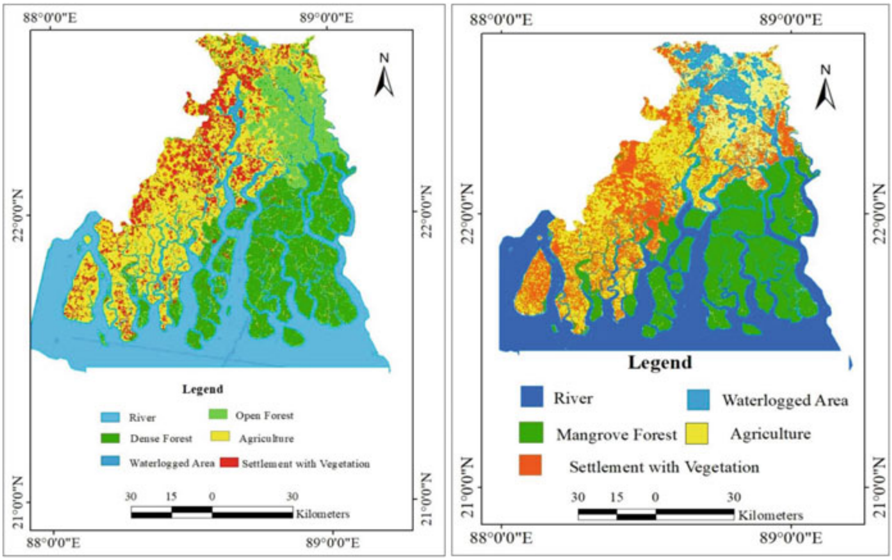


Fig. 16.4 Land use and land cover of Sundarban of 1975 and 2014

Therefore, it reveals that the mangrove dynamic was more prominent in core and buffer area of the forest, mostly due to the natural calamities, land loss, and anthropogenic causes. Moreover, it has also been noticed that the forest area was reclaimed for agriculture in the initial period, but later some of these agricultural lands were transformed to aquaculture water bodies, some were occupied by settlements, and some of the forest cover, vegetation area, and sandy area were even transformed to settlement area which signifies enormous anthropogenic encroachment in the Sundarban. Whenever forest destruction or coastal erosion, flooding, etc. occur, people are reclaimed or acquiring some land for agriculture or converting agricultural land into aquaculture or something else, which is suited for them and equipped with the situation.

16.4.4 Depletion of Sundarban Mangroves and Related Issues

SBR is famous for its unique mangrove vegetation, and the main forest area is categorized into core zone, 1692 sq.km.; buffer zone, 7693 sq.km.; and transition zone, 245 sq.km. Buffer zone has the highest proportion of area than the core and transitional area and probably is mostly exploited by the inhabited community. The marshy saline soil, damp climate, and inundated tidal water help to develop the mangrove plants particularly in the coastal areas. Among the numerous species, *Sundari*, *Garan*, *Genwa*, *Hital*, etc. are very special in terms of ecological and economic value (Chowdhury et al. 2016). Thus, mangroves of Sundarban appear

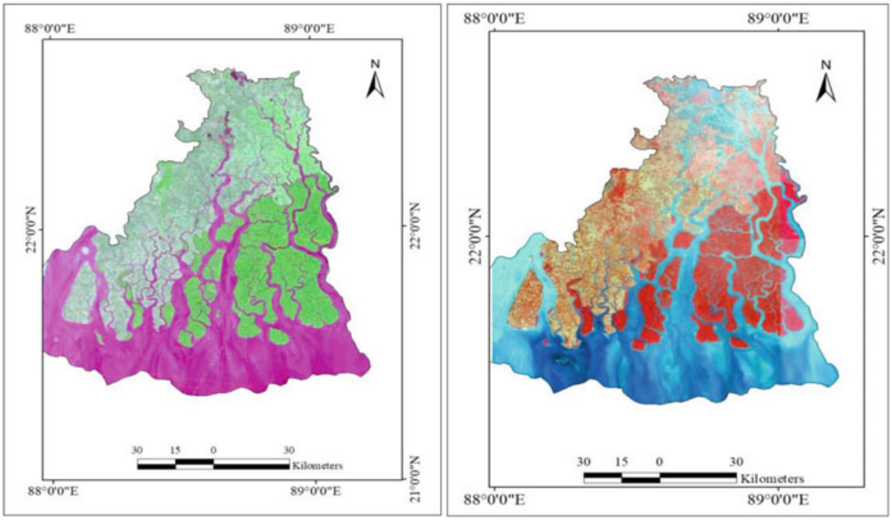


Fig. 16.5 Satellite images of Indian Sundarban Delta, 1975 and 2014
Data source: Map, 1975 (USGS: Landsat 1 MSS, 1975); Map, 2014 (USGS: Landsat 8 OLI, 2014)

as unrestricted public and common pool resource for most of the local people, and it has often become the tragedy of the commons when they fail to control the exploitation of such resources. The satellite images (False Colour Composite) of mangroves of the Sundarban of the year 1975 and 2014 have been portrayed (Fig. 16.5) to understand the bird's-eye view at a glance.

The depletion of mangroves of Sundarban over the years was mapped using geospatial technology, and it indicates a drastic change from 1776 to 2014. The mangrove dynamics were clearly depicted in the map starting from the Rennel to the modern satellite-based mangroves forest cover of Sundarban, especially 1776, 1873, 1975, and 2014 (Fig. 16.6).

It was found that initially the Sundarban area was settled by cutting the mangroves and/or reclaimed which aggravated in the later phase, and after independence, decrease of mangrove forest-covered area and its intensity were noticed. The increasing trend of population concentration over the area, their dependency on the forest resources, and other anthropogenic effects are the root cause of such mangrove depletion (Chowdhury and Maiti 2014, 2016). The mangroves of the Sundarban support important subsistence fisheries causing extensive deterioration of the ecosystem chain due to the excessive use of the ecosystem resources. Furthermore, the periodic cyclones cause high human mortality and production losses, and the damages and breakage of the river embankment cause saline water incursion into the agricultural lands resulting in loss or low agricultural productivity. Therefore, it often forces people to depend heavily on the ecosystem resources of mangroves to meet their livelihood needs. Thus, the anthropogenic activities often damaged mangrove forest and ecosystem as a whole through rapid depletion of such resources.

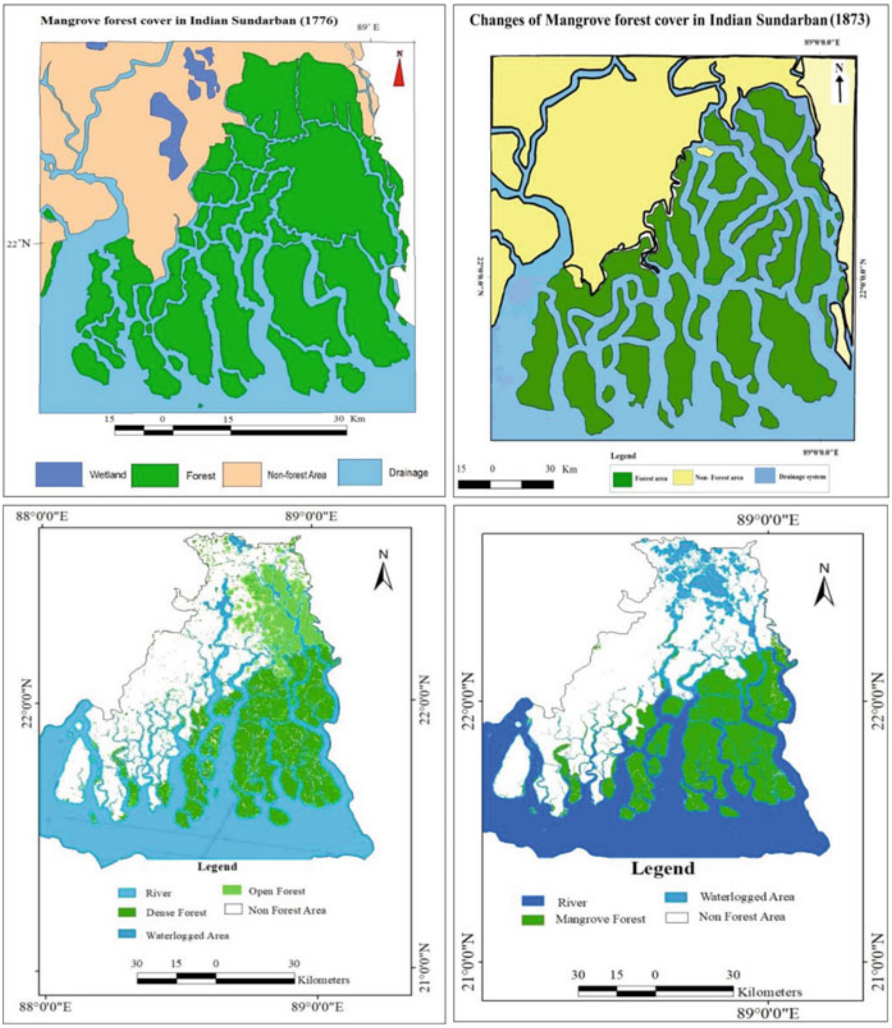


Fig. 16.6 Changes in mangrove forest cover in Indian Sundarban (1776, 1873, 1975–2014) Data source: Map of 1776 (Rennel 1780); Map of 1873 (Statistical Account of Bengal 1873); Map of 1975 (USGS: Landsat 1 MSS, 1975); Map of 2014 (USGS: Landsat 8 OLI, 2014)

16.4.5 Livelihood in Sundarban

The majority of the inhabitants of Indian Sundarban are dependent on primary activities for their livelihood, and agriculture is the prime focussed activities, among them, and more than 80% populace are inclined to agriculture (Hajra and Ghosh 2018). The situations are getting more adverse when a sort of hazard is hitting the area because of the embankment collapse, saline water inundation, water stagnation, and crop damage, and some other related issues aggravate the vulnerability. Thus, due to such kind of negative impact on the agricultural sector, people are becoming inclined to wage labour and frequently choose to migrate apart from fishing and the collection of prawn seeds and honey particularly during agricultural lean season. In such consequences, the presence of a huge population has posed enormous pressure on nature and the resource base of SBR. Moreover, environmental induced immigration, especially during the cyclone attack boosting the existing vulnerable situations and enhancing the risk for livelihood for sustain. Any extreme environmental events related to climate change have larger persuade on those sections of the society that are most reliant on natural resources for their livelihood in Sundarban. The weaker section of the population has the least capacity to respond to hazards like super cyclone, flood, etc., and they often face higher risk and greater burdens due to hazardous circumstances with having poverty.

16.4.5.1 Major Economic Activities in Sundarban: Agriculture

Agriculture is considered as the backbone of the economy of Sundarban as more than 80% people (Hajra and Ghosh 2018) are diversely associated with the largely important economic sector. Agriculture is being operated in the traditional way in the reclaimed land which consumes a large proportion of poor people, and the agricultural land is surrounded by embankments to protect the inflow of tidal saline water of the river. The area is penetrated by inadequate irrigation facilities, leading to monocropping agriculture, which again hamstrung by salinity through both ground water and surface water of entire Sundarban. Agriculture is the stronghold of the economy of the Sundarban despite its geophysical adversity along with the fact that 55 percent of the population is landless. Even the marginal and small farmers as apparent in the Sundarban are a little notches below that defined by the state (Mandal et al. 2013). The marginal farmers have a land holding of 0.13 to 0.27 hectares (1–2 *bigha*), while a small farmer has a land between 0.27 and 0.67 hectares (2 and 5 *bigha*). Moreover, in Sundarban, about 54.21 percent have been recorded as landless labourers, and 85.22 percent are small and marginal farmers with an average holding of 0.82 hectares per family (District Statistical Handbook), and the generally requisite capital investment in the sector is not taking place. Because of the overdependency on such primary activities, the cultivable lands are becoming susceptible day by day, and people are hunting the alternative source (WWF 2010; Sahana and Sajjad 2019; Laha 2019). Currently, due to the negative impact of climate change-induced hazards, especially in the economic sector, people are engaging themselves in fishing, collection of prawn, and collection of honey, risking their breathes from man-eating tigers and crocodiles particularly during agricultural lean season (Dutta et al. 2019). Coastal and brackish water fisheries of Sundarban provide a distinct source of income for the people, particularly for small and marginal farmers.

Agricultural Productivity and Efficiency

Maximum inhabitants of Sundarban depend on agriculture for their livelihood; still the cropping intensity of Sundarban is low in contrast to other parts of West Bengal. Most of the cultivable land is devoted to paddy production, whereas vegetables and pulses are also grown to depend upon the market demand. The season-wise cropping pattern is important for the inhabitants as most of the land is monocrop and mostly mono-usable. Agricultural productivity is the combined function of a number of factors which manifest the overall productivity per unit area, and mostly it is the outcome of combinations of infrastructural elements, and thus categories of agricultural efficiency zones have been attempted and tabulated below (Table 16.5).

Concentration of Agricultural Labours

Very rapid and steady decrease of land by the tidal waves, often inflow of saline water into the farms, and a concomitant steady increase of population pressure in Sundarban make the area's agriculture a hard task. Therefore, to understand the concentration of agricultural labourers, standard score has been calculated for all the blocks of Sundarban. The calculated standard score value of agricultural labourers ranges from −1.24 (occupied by Joynagar I block) to +2.21 (occupied by Basanti) which signifies a large variety in concentration of agricultural labourers. The map

Table 16.5 Agricultural efficiency of Sundarban

Degree of efficiency	Blocks	Crop production
Very low	Mathurapur I, Joynagar I, Minakhan	Due to low fertility (in the case of Minakhan) and low irrigation facility and increasing rate of non-agricultural use of land (in the case of Mathurapur I and Joynagar II), the mentioned blocks of North and South Sundarban exist in this zone
Low	Haroa, Hingalganj Hasnabad, Gosaba Sandeshkhali I	These blocks suffer from lack of irrigation and rain-water harvesting with advance technology. The blocks have the potentiality for better production, and for that, proper maintenance and opportunity is needed
Moderate	Kultali Patharpratima Sandeshkhali II	The mentioned blocks mainly stand in this zone because of their paddy production. Vegetables and other crops are also produced for sustaining their daily needs
High	Mathurapur II, Kakdwip, Sagar, Joynagar II Canning I, Canning II	Season-wise and different types of paddy and cereal crops are produced significantly in these blocks
Very high	Namkhana Basanti	Alluvial soil and other environmental conditions are favourable for high production of paddy and other crops. Recently, improved transport system boosts the agricultural sector in the blocks

Source: Author

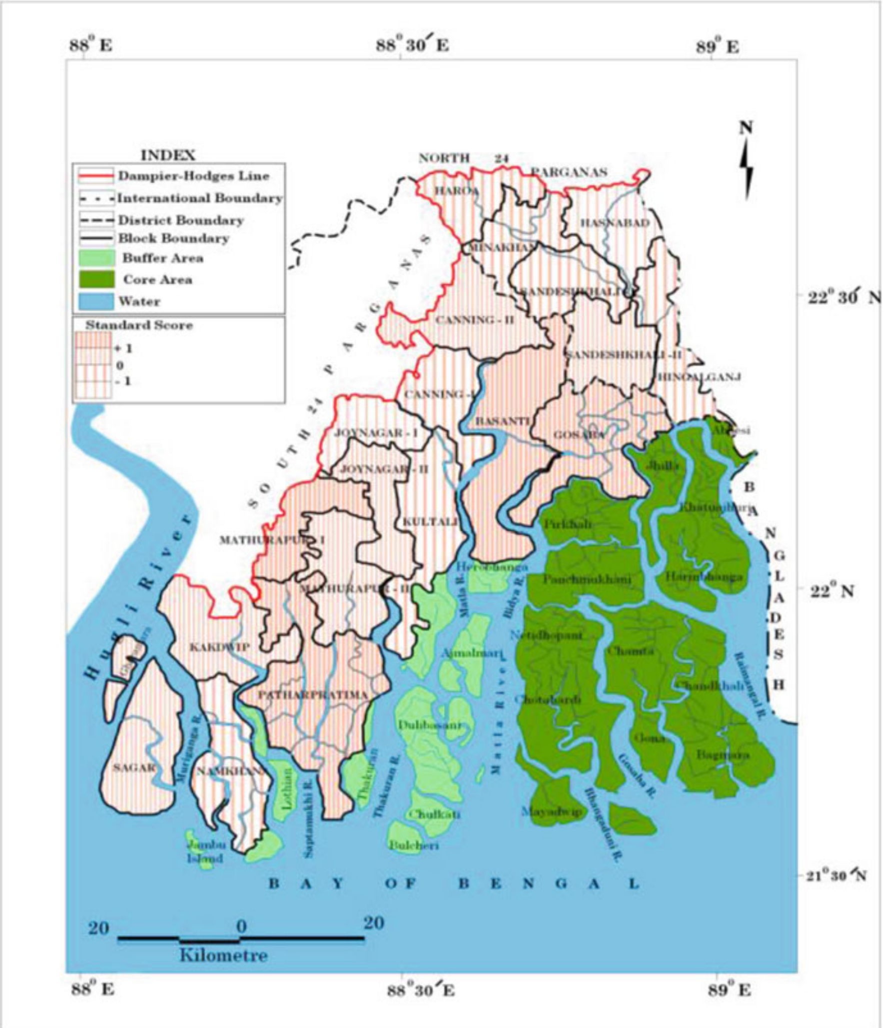


Fig. 16.7 Concentration of agricultural labourers

(Fig. 16.7) reveals that Basanti, Gosaba, and Patharpratima blocks belong to very high and Sagar, Canning II, Joynagar II, Kakdwip, Mathurapur II, and Sandeshkhali II blocks belong to high, whereas Canning I, Namkhana, Mathurapur I, Kultali, Haroa, Hingalganj, Minakhan, and Sandeshkhali I fall out in moderate category, and Joynagar I, Mathurapur I, and Hasnabad belong to low category of concentration of agricultural labourers.

Proportion of Agricultural Labourers and Workers

The proportion of cultivators and agricultural labourers is very high as in respect to the workers in household industries and other workers (Fig. 16.8). Moreover, agricultural labourers occupy a greater percentage (55%) than the cultivator in Sundarban, and there have a good number of landless labourers. The landless labourers work in terms of money or personal benefit as an agricultural worker or

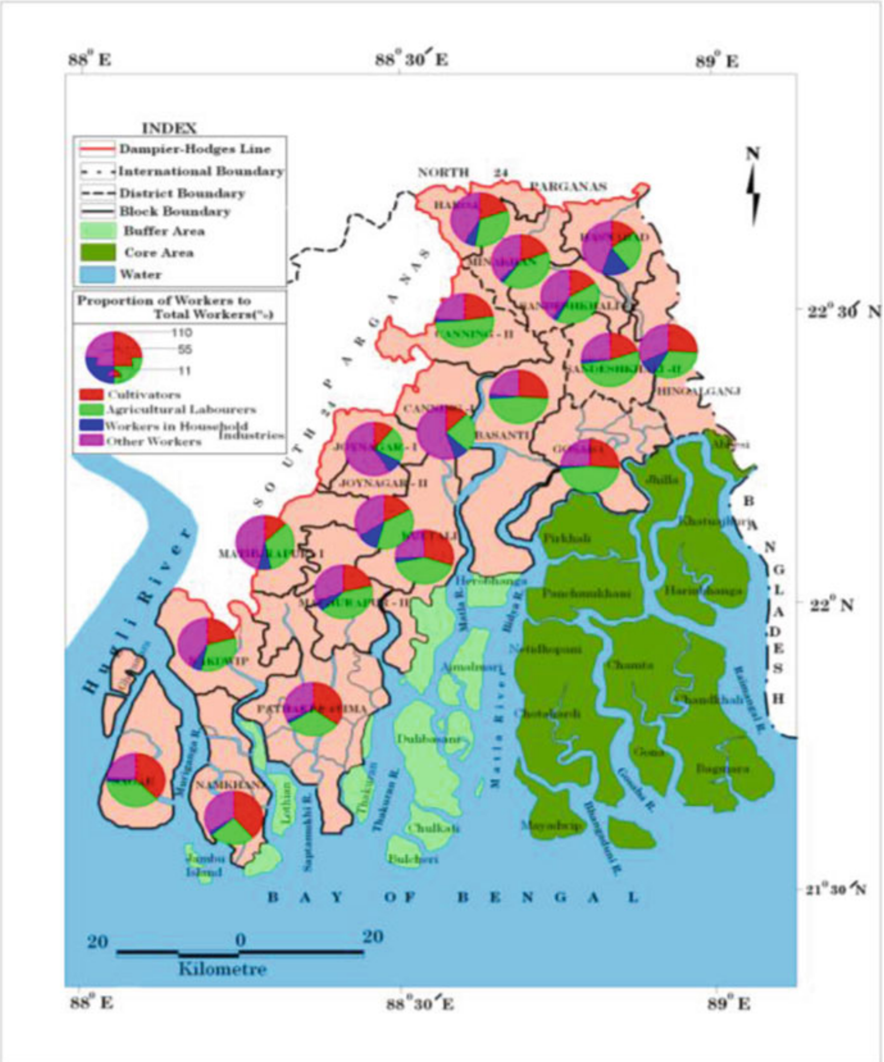


Fig. 16.8 Proportion of workers
Data source: District Statistical Handbook

marginal workers in those agricultural fields. The landowners distribute their lands for cultivation to those labourers in terms of some money, and they are engaging themselves in some other money-earning process. The percentage of agricultural labourers is maximum in Sandeshkhali II, Canning II, Basanti, and Gosaba and minimum in Joynagar I. The proportion of the cultivator is more in Namkhana, Sagar, and Patharpratima which signifies that the population of these blocks engaged in the cultivation of paddy, food grains, or vegetables with a greater percentage than the other blocks, whereas maximum people of Joynagar I block engaged in other occupation than cultivation-related activities, mainly in household industries. People of Sagar, Sandeshkhali II, Kultali, Basanti, Gosaba, and Canning II blocks mostly engaged in various primary economic activities.

16.4.5.2 Minor Economic Activities in Sundarban

Fishing and Honey Collection

The inhabitants of Sundarban are closely associated with the fishing and honey collection as their prime source of income which is considered as the minor economic activities. All the rivers are free from pollution and are sources of huge quantity of fish, and thus a large number of people (women, men, children) are engaged in collection of prawns and fishes using nets (Mukherjee et al. 2012). The demand for tiger and other prawn is on the rise, and they are indiscriminately exploited, since they fetch a high price in the market. Moreover, the process of catching and isolating prawn seeds from other varieties of fish destroyed many other valuable marine species. In such process, mangrove forest area protection has been neglected and cleared. In several parts of the Sundarban, mangroves are converting brackish water prawn farms to the utter neglect of the natural laws and rules of succession and/or sustainable productivity of the natural ecosystem.

Honey and Wax Collection

One of the traditional and seasonal livelihood activities of Sundarban is the collection of honey, wax, and timber/fuel wood from the mangrove forest area. More than one thousand people of Sundarban are engaged in this livelihood activity, and on an average, 60,000 kg. honey is being collected each year. About 120,000 quintal/year timber and fuel wood are collected from the forest. The Sundarban mangrove contains various honeycomb trees, like *Genwa*, *Goran*, *Garjan*, *Bain*, etc. The contribution of these trees in honey production is 39, 11, 10, and 16 percent, respectively, and they serve as an ecological input. Non-tribal Muslims and tribal Lodhas and Mundas were the traditional honey collector of Sundarban. Later, the schedule caste people also engaged in this activity and acquired this traditional skill and became an integral part of that seasonal activity. The honey and wax collectors lend money from the moneylenders for a permit from the Forest Department, hire the boat, etc., and are often compelled to retail their entire collection at a very low price. Thus, the collection of honey in the area became one of the foremost seasonal activities, and the Forest Department usually issues about 1000 permits every year, and the permit holders are allowed to access the buffer zone of Sundarban. The onset of monsoon, i.e. March to June, is the honey collection season, and bulk honey is produced and collected in the phase. The honey collectors are referred to as 'moules', and mainly Lodhas, Mundas, and non-tribal Muslims are the traditional honey collectors in the region. Later the immigrants to the region, the scheduled caste people, gradually acquired the traditional skill, and thus honey collection became an integral part of their seasonal activities. The moules are mostly concentrated in the fringe villages of Gosaba, Kultali, Patharpratima, and Hingalganj blocks of Sundarban. But, this profession has a fatal risk of life from the attack of the tiger or crocodile in the deep forest, and almost the same fate is frequently met by the woodcutters and fishermen. The maximum extent of man-eating by tiger takes place in the area during the season (April–May) of honey collection and peak salinity of the creek water. The incidence of man- animal conflict has raised with eventual fatality and thus the extent of death either by the tiger or crocodile (annual death average: 20–25 persons) attack or snake bite (annual death average: 130–150 persons) is the fate that the inhabitants. In the entire Sundarban, there are a few pockets in every island inhabited by the bereaved wives of those dead people, known as *Bidhoba Palli* (village of the widows) (Fig. 16.9), and their poverty, social neglect, depression, and poor quality of life make their life in sorrowful state.

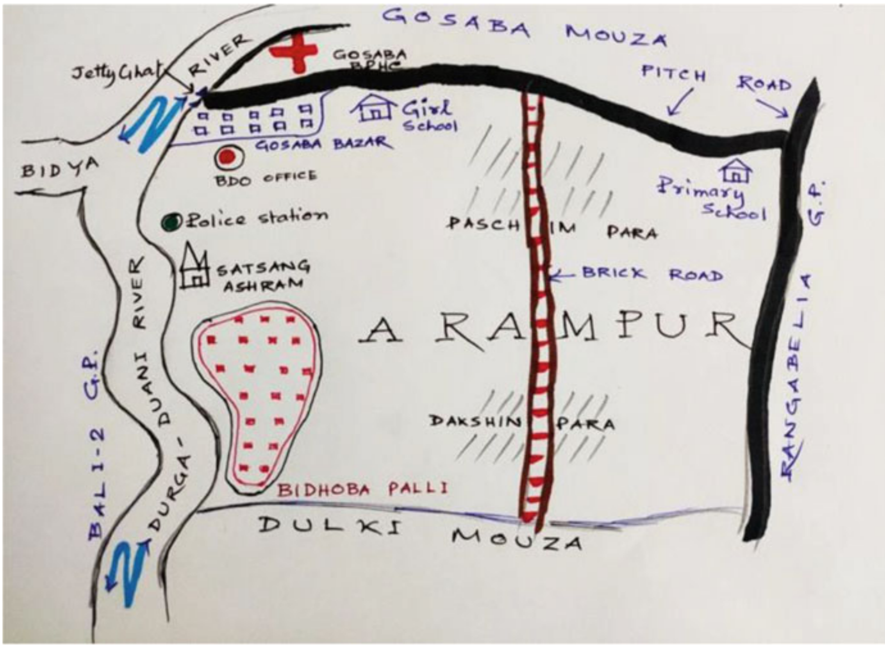


Fig. 16.9 Social map of Arampur Mauza, Gosaba block, of SBR

16.4.6 Application of Participatory Rural Appraisal (PRA) Technique

Participatory rural appraisal (PRA) emerged in the 1980s as a continuum of rapid rural appraisal (RRA) and field-based, people-oriented approach. It is a participatory tool of learning and is applied in planning, implementation, monitoring, and evaluation. This tool not just commits the people in appearing and analysing their problems, conditions, etc. but also extends into analysis, planning, and action forward; henceforth, it is considered to be applied in Sundarban for the current study. This PRA is an innovative approach and method which engaged rural people to do much of the investigation, presentation, analysis, planning, and dissemination (Mukherjee 1997; DasGupta and Shaw 2013). The inhabited people of Sundarban are the key and primary stakeholders in the development process, and they play a very significant role in deciding their future and destiny. Thus, during the execution of PRA in Sundarban, all the respondents were informed about the nature of the study before proceeding with the interview and survey, and thereafter participation in the research was voluntary, and people understood the philosophy of PRA that lays stress on awareness and enables the local poor people to share, enhance, and analyse their conditions and knowledge of life and to plan, act, monitor, and evaluate. It provides an enormous scope and room for both Sundarban people and outsiders to actively participate in the development. It also empowers the weak, the powerless, and the marginalized section of the society, by enabling them to analyse, talk about, and be conscious of their conditions through its interactive process and mutual learning. Thus, it is very much helpful to access the dynamics of forest and dependent stakeholders for the overall rural development of the Indian Sundarban. The application of PRA in Sundarban for the current effort is intended by the following techniques:

16.4.6.1 Participatory Mapping

The rural people of Sundarban have a clear image of their village and its surroundings, as they are interacting continuously with their surrounding environment. They can easily transfer the picture from their mind in the form of a map, and that participatory mapping facilitates the people an understanding of their situation and condition. The mapping refers to the drawing of map by which information is presented in spatial forms by the people of the community, and this map promotes community cohesion and self-actualization, effectively making a dynamic tool to aid communication (Mukherjee 1997). In Sundarban, the execution of such map helps to create a framework of the comparative position of local resources; to emphasize the resources and their spatial guide; to raise the issues and circumstances; to analyse the present position of these resources and their effectiveness; to create awareness in the community about the importance of these resources; to create a focus of interest over the resources; to stimulate over the relative importance and their spatial factors of resources; to develop a basis for comparing different perspectives of social and resource-based maps; to create visual presentation which is understood by every villager; and to stimulate the villagers for impact analysis, assessing some change and monitoring and evaluating the rural development of Sundarban. It also gives useful insights into the realities of livelihood, activities, and mangrove forest dependency which could be incredibly constructive in maintaining forest health, in conserving the forest and wildlife, as well as in policy framing.

Social Map

In Sundarban, the social map is conducted as a mapping exercise and used to present information on the village layout (Fig. 16.9), infrastructure, population distribution, health care, social stratification, and so on. This map also includes health, water and sanitation, education, leadership, vulnerability, and indigenous skill maps, and the applicability of it is much more, and it creates a suitable atmosphere where the outsiders and the villagers get closer to establish a good rapport and help to understand the educational standard, the socio-economic background, etc. If these social maps are integrated into the planning process, then the vulnerable and depicted section of the community is integrated in the development process. This map is effectively used in Sundarban and is found helpful in identifying the most vulnerable section of the village community in Gosaba block, and it is usefully employed for the solution of various local problems, well-being analysis, livelihood analysis, and other purposes and is incorporated in the planning process.

Resource Map

The resource map, by and large, is used to present information on land; water resource; land use and cropping pattern; productivity; land, soil, and water management; degraded lands; etc. In Sundarban, this map helps to ascertain forest resource status and extent of exploitation of resources (Fig. 16.10), finding out ways and means for conserving and improving the existing forest and other resources of the study villages. This thematic resource-oriented map, like agriculture, water resource, and forest maps, is used to depict the agriculture, water sources, land use, resource utilizations, forestry, cropping pattern, etc. of Gosaba block. This map helps to analyse the problems of forest changes, find out its cause, and create a way for sustainable management. This type of map ascertains the opportunities and problems associated with forest resources, engaging the local people in the identification and evaluation of such resource act as a powerful tool of participatory planning.

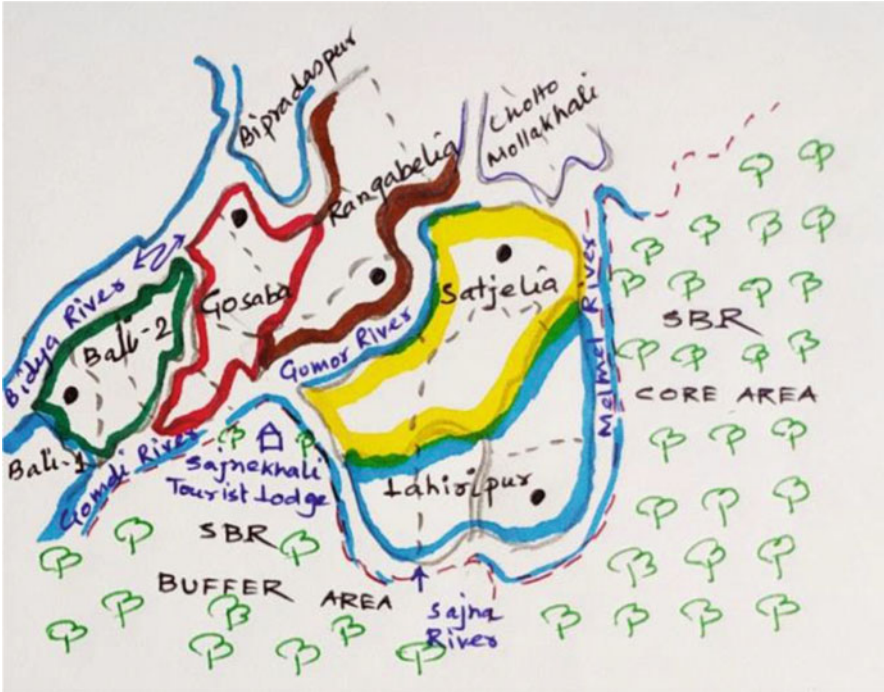


Fig. 16.10 Resource map of Gosaba block (south part) of SBR (based on primary survey, 2019)

16.4.6.2 Transects

The transects have been used to explain the spatial dimensions of veracities by a cross-sectional outlook of the diverse areas of Sundarban in an effective way, to study regarding rural life and the improvement, predominantly about the multifarious interface between man and the surrounding environment, of forest resources and their management and forest-based livelihoods.

As an outsider of PRA practitioners, I don't have a better, deeper, and more comprehensive analysis of the resources; therefore, I leisurely walked in and around the village, walked through the fields and directly observed the resources of various types, and learned gradually from the people. Through the transect walk, I got insights and information about the nature and complexity of the existing scenario. I took transects as an observatory walk across the field of rural area of Sundarban during the field survey to study in depth the natural resources, topography, soil, vegetation, etc. (Fig. 16.11), and during this transect, observations are made at different location, such as the coastal lands, midlands, and lowlands.

It is usefully applied in land use pattern, soil erosion, irrigation system, cropping pattern, social forestry, community forestry, biotic pressure on forests, pressure of animals on people, wetland management, etc (Sahana et al., 2022). Therefore, in Sundarban, transect is used to appraise the condition of mangrove forest and its

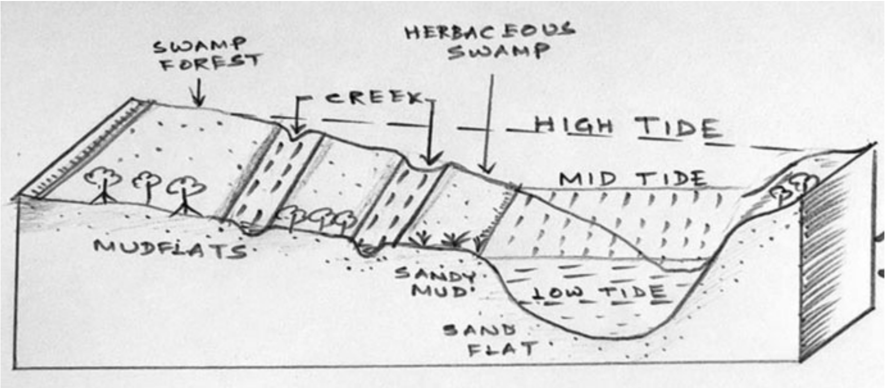


Fig. 16.11 Sectional view of mudflat in Pakhiralay, Gosaba block, Sundarban (based on primary survey, 2019)

Table 16.6 Transect based matrix of PRA

Resource system	Livelihood conditions	Mangrove forest and nearby water bodies	Sea resource
Resource	Small piece of land around each house, lack of personal resource	Mangrove wetlands, sand dunes, creeks, fish, prawn, crabs, etc. in water	Fish, prawn
Activities	Little farming, wood and honey collecting, less engaged in other activities, fishing	Fishing in the mangrove waters mainly for saline fish and prawn, seasonal variety of activities	Fishing by traditional methods
Problems	Often affected by hazards, like flooding, cyclone, earthquake, saline water, communication problems, etc.	Traditional fishing practice, lack of fishing equipment, overdependence to forest area, poor and low caste people	No special boats and nets for sea fishing
Opportunities	Traditional and institutional mechanisms, but well experi-ences exist	Community interest in man-grove conservation, large resource base	Gradual increase of sea fishing
Perceptions	Unsuitable living conditions	Mangroves must be conserved as these are the main resource of the area's livelihood	A future source of livelihood

Source: Prepared by the author (based on primary survey, 2019)

conservation and management purposes as it identifies the resources used by the inhabited community, the resource availability, and its ownership and use system and notifies and marks the perception of the villagers about the resource systems, utilization, strengths, and problems in utilizing these resource opportunities for development. Thereafter, a transect-based matrix has been prepared to gather various information during the mangrove resource and indicate the backwater fishing resource associated with the mangroves and its impact on the environment and the livelihood pattern of the villagers in Gosaba block (Table 16.6).

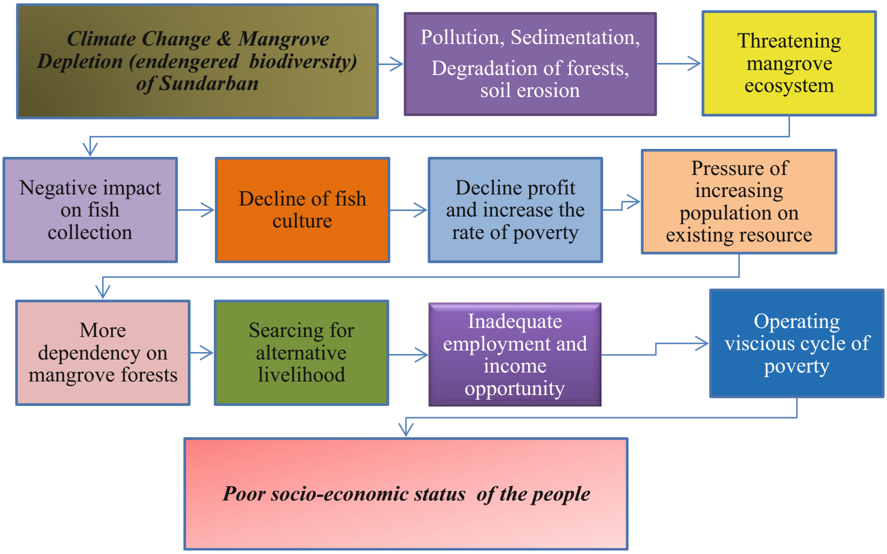


Fig. 16.12 Flow diagram of mangrove depletion and related issues
Source: Prepared by the author (based on primary survey, 2019)

16.4.6.3 Flow Diagrams

This planning and evaluation tool is applied to assess the cause and effects of climate change and to assess mangrove dynamics, highlighting the gaps of potential connections of developmental scenario in Sundarban (Fig. 16.12). This flow diagram depicts the mangrove depletion and its causes and identifies the negative aspects and impacts, the interlinkages, and the relationships of the associated issues.

16.4.6.4 Seasonal Calendar

The employment of this diagram in Sundarban provides a trend in the main activities, vulnerability, livelihood patterns and related problems, and opportunities of the living community throughout the year. It is currently used to portray the monthly income of the people associated with agriculture, social and community forestry, and fishery to understand the livelihood standard of some selected villages of Gosaba block (Fig. 16.13). Moreover, the month-wise depiction helps to identify crop sequences, from planting to harvesting; to examine the effect of climate on the livelihood pattern; to study the income-generating activities; and to examine the months of great strain and stress, etc. of the study villages. It provides a vivid picture of difficulties and vulnerability of the village community of Sundarban throughout the year and is used in assessing seasonal variations in various economic activities for improvement.

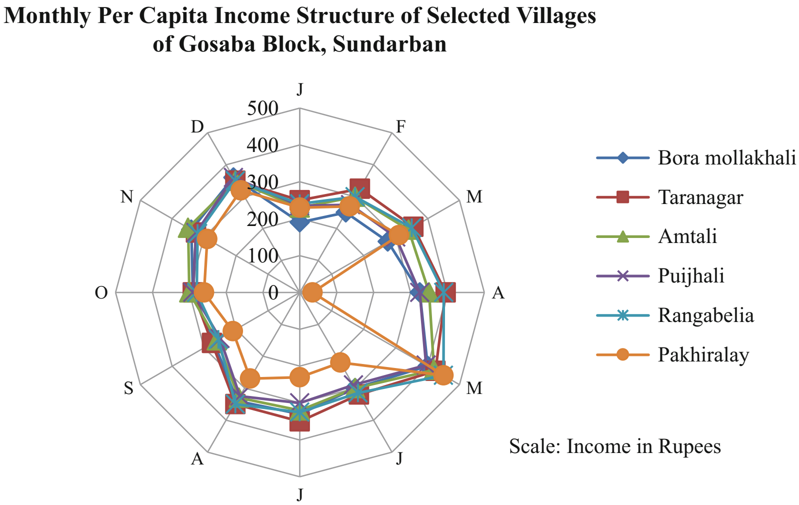


Fig. 16.13 Seasonal calendar of monthly per capita income structure of Gosaba block
Data source: Primary survey, 2019

16.4.7 Micro Level Appraisal: Account from Gosaba Block

16.4.7.1 Statistical Accounts of Gosaba Block

An in-depth micro level study was conducted to demonstrate the PRA methods and portray the issues of livelihood and adaptation challenges that are faced by the forest-dependent people in a very much vulnerable block, i.e. Gosaba, located in a fringing position, close to mangrove forest.

According to the climatic vulnerability and risk zonation map, this block belongs to highly vulnerable or very risky zone with respect to any climatic events even though it is often considered as one of the least accessible blocks of Sundarban in terms of connectivity and remotely located island position (Fig. 16.14). The brief statistical accounts of the Gosaba block are as follows: entirely rural area; 15 Gram Panchayat (GP); 51 Mouzas; moderate population density (825 person/sq. km.); moderate decadal population growth rate (8.83%); overly dependent on primary economic activities, like agriculture (70%) and fishing (20%); high concentration of poor households. Moreover, as most of the households are thatched and kutcha (80%), they are vulnerable; less than 2% households are having electricity; telecommunication facilities and connection levels are not satisfactory. Consequently, here the lives are in isolation by the criss-cross drainage network, and livelihood opportunities are very much restricted.

The three primary survey villages are (1) Rangabelia GP, Pakhiralay Mouza (22.142079° N, 88.829524° E); (2) Amtali GP, Puijhali Mouza (22.223345°N,

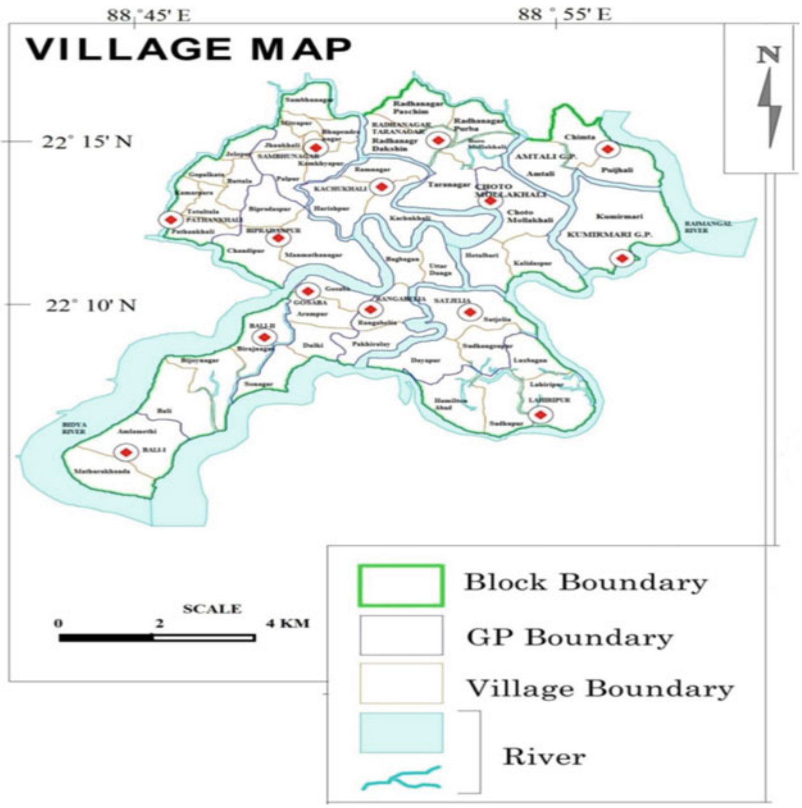


Fig. 16.14 Village map and Gram Panchayat offices of Gosaba block

88.83164°E); and (3) Radhanagar Taranagar GP, Boramollakhali Mouza (22.2318461°N, 88.85417474°E). The brief details of the study GPs are tabulated below (Table 16.7).

16.4.7.2 Environment and Dependent Livelihood of Gosaba Block

As the Gosaba block is entirely surrounded by rivers and earthen embankments, the coastal exposure is very high, intended to increase the challenges during hazards. Many of such embankments and roads are destroyed during Cyclone Aila (2009) leading to prolonged flooding, saline water stagnation, and damaged agricultural land (Kar and Bandyopadhyay 2015) along with the existing issues of man-animal conflicts due to close location to forest. Thus, the block frequently exposed to all sorts of hazards and entire area remains vulnerable and risky as it is experiencing cyclone, sea level rise, coastal erosion, changing river course, saline water inclusion, and many more. In terms of infrastructural setting, the block is facing tremendous troubles as there is no formal motorized public transportation and they are very

Table 16.7 Statistics of study Gram Panchayat of Gosaba

Gram Panchayat (GP)	Mauza	J.L No.	Total population	% of ST
Radhanagar Taranagar	Dakshin Radhanagar	31	3605	13.40
	Paschim Radhanagar	32	3804	9.91
	Purba Radhanagar	33	3072	11.89
	Boramollakhali	34	3225	17.77
	Taranagar	41	5504	15.99
Amtali	Amtali	35	5044	2.90
	Chimta	36	5016	12.36
	Puijhali	37	4236	10.56
Rangabelia	Rangabelia	25	3002	6.83
	Bagbagan	26	2848	5.03
	Uttardanga	43	3104	9.86
	Pakhiralay	24	3257	1.31

Data source: Census of India, 2011

poorly connected through semi-mechanized boats and motorized engine van. Most of the roads are non-metalled, and the condition of such roads and jetties are getting worse during the rainy season; thus we can easily guess its position in hazardous circumstances. Henceforth, implementation of any kinds of policies and developmental schemes is very critical in the block mostly due to physical isolation, and unawareness of people about different related issues also plays a vital role in this regard.

The percentage of cultivable area to total area in Gosaba block is 78.11, and the cereal yield is 2831.80 kg./hectares, whereas 10.81% of total area have the opportunity of net pisciculture; net area available for pisciculture is 4282 hectares, and net area under effective pisciculture is 3208 hectares; thus the values signify that this block is dependent on agriculture and fishing and is specifically more inclined to pisciculture in recent times. Agriculture in the islands of the block is quite a hard task because of the high salinity of soil, heavy rain, and storm incidences. Thus, the cultivable area is gradually declining mostly due to the partition of land and the establishment of new human settlements. Unpredictable flood is a recurrent reason for crop failure and often intensifies human sufferings. There are no irrigation facilities; the mono crop paddy cultivation is totally dependent on rain and thus the productivity of paddy (aman) has negatively related with rainfall as the climate change and related excess rainfall declining its productivity. Moreover, inadequate drainage during monsoon, saline water inclusion, and water logging create problems very frequently to agriculture.

It reveals from the graph (Fig. 16.15) that the working groups are mostly main worker, cultivator, agricultural labourers, marginal and other worker, and household and industrial workers and a large proportion remains as non-working among which females are acquiring double in number than their counterpart. Here, the household and industrial workers are very insignificant, and the proportions of agricultural

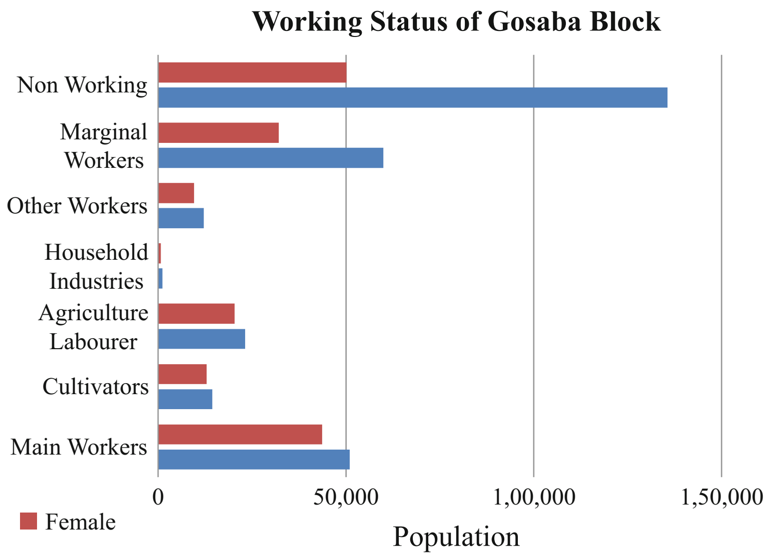


Fig. 16.15 Working status of Gosaba block

labourers are more than the cultivators which signifies the landlessness of the population of the block.

In the study villages, more than 70% of the population are landed peasants, and more or less only 5% people have own land despite having four to five members in a family (Fig. 16.16). That signifies a stress figure of man-land ratio. The man-land ratios of the three study villages are 5:3 in Pakhiralay, 4:2.5 in Puijhali, and 5:2 in Boramollakhali.

The majority of the inhabitants in the area are spending their time working in agricultural land and riverside, fishing, and going to the forest and in some unpaid household activities. It reveals from the primary survey that above 30% belongs to agricultural activities, followed by fishing and prawn seed collection (above 20%), succeeded by livestock in all the three study *Mouzas*, while a less proportion is engaged in daily wage, business, and job including tourism (Fig. 16.17).

Gosaba block has a notable LULC change over the period of 2001 to 2010, and it is established that all LULC types were transformed, and the foremost alterations were initiated in the settlement area with vegetation and fallow land as both of them increased, while the mangrove forest was reduced, followed by agricultural land and water bodies (Fig. 16.18).

Moreover, it is found that agricultural land has further been reduced as the settlement area capturing the lands. The close location of mangrove forest makes the inhabitants inclined towards the forest resources, and probably they are clearing the mangroves and preparing for settlement or aquaculture as per their requirement.

The situation is often distorted after any super cyclone hit, like the attack of Cyclone Aila in the area, as found from several researches. The LULC of 2009 just

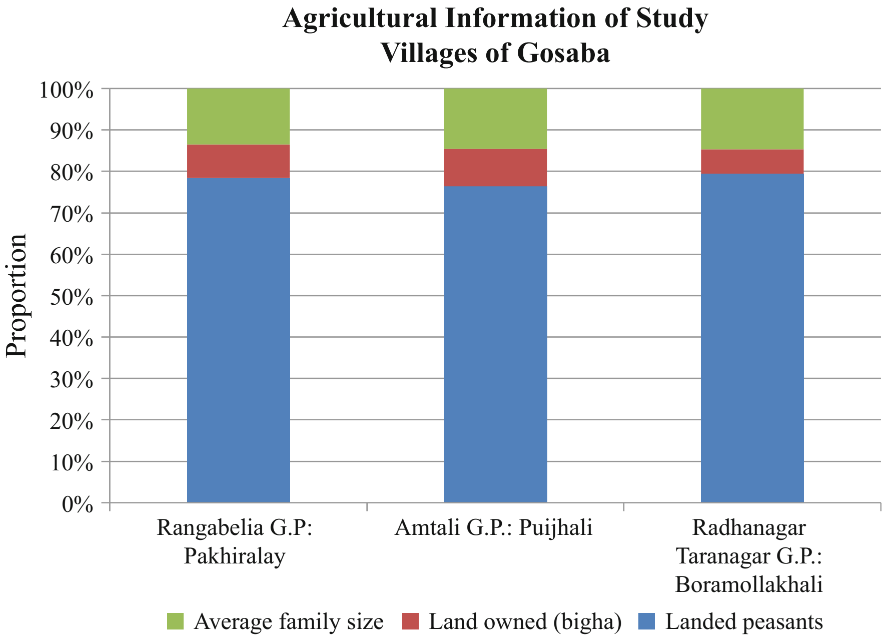


Fig. 16.16 Agriculture of Gosaba villages
Data source: Census of India (2011) and primary survey (2019)

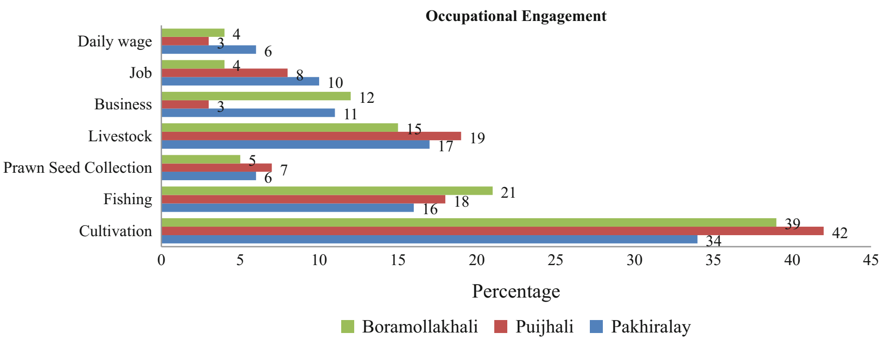


Fig. 16.17 Occupational engagement
Data source: Primary survey, 2019

after Cyclone Aila has drastically changed as the salt water inundated the land for several days (Kar and Bandopadhyay 2015, 2016; Das 2016; Debnath 2018; Ghosh and Mistri 2020). Most of the areas of the entire block have below 10 m altitude, and there are several earthen embankments besides the criss-cross drainage network, which are easily damaged and collapsed due to the attack of Cyclone Aila and because the saline and turbid water encroached in the agricultural field. The north-

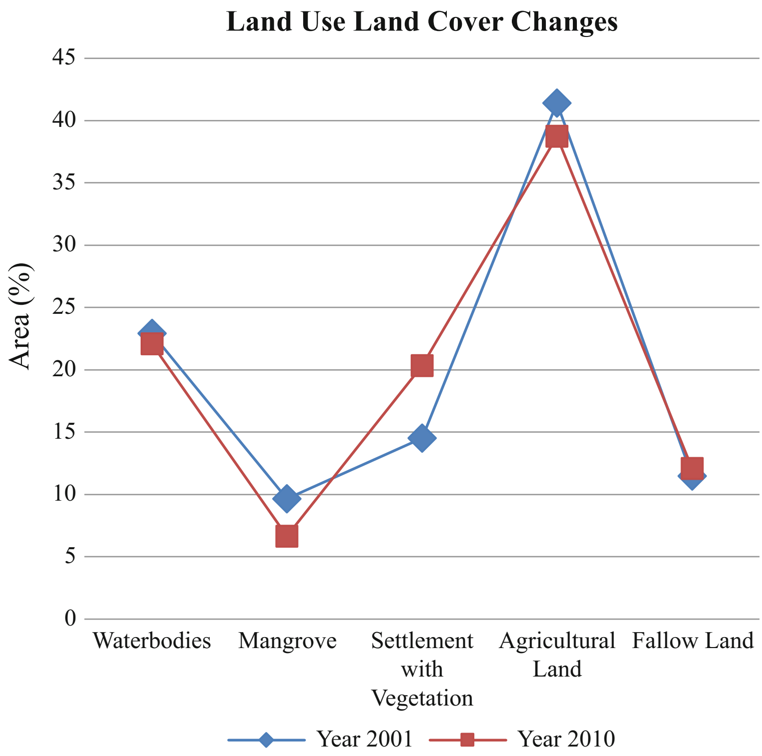


Fig. 16.18 LULC changes of Gosaba block

western part of the block had some cropped area and fallow land with grass during the post Aila period for a long time, and the rest of the block area had been inundated by less turbid water and highly turbid water behind the embankment parts. The entire block area was inundated from 25 May almost up to October, 2009 which consequences less land for crop after that, less proportion of land remaining dry and the huge wet area made the situation worst even after October, 2009 and about two months of 2010. This situation even aggravated some islands of the block due to low altitude and the existence of more embankments, and thus the overall subsequent recovery from this situation was quite challenging, and as a consequence, rice production was reduced to 32–40 quintal from 64 to 80 quintal per 1.6 hectares (Debnath, 2013; Halder and Debnath 2014). The very recent (July 2020) LULC classification of the Gosaba block has been prepared to understand the overall and recent changes by using ArcGIS 10 and ERDAS IMAGINE 9.2 software retrieving the satellite images from USGS 2020 (Landsat 8 OLI data) (Fig. 16.19). The map portrayed the agricultural land, fallow land, habitation with vegetation, mangroves, and river and water bodies, and it revealed that major proportion is covered by either agricultural land or settlement area.

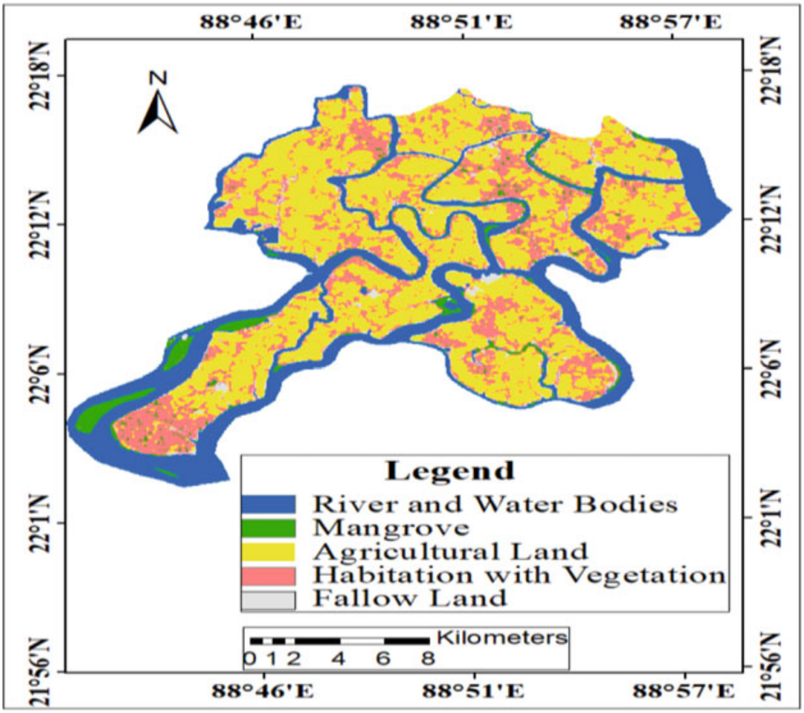
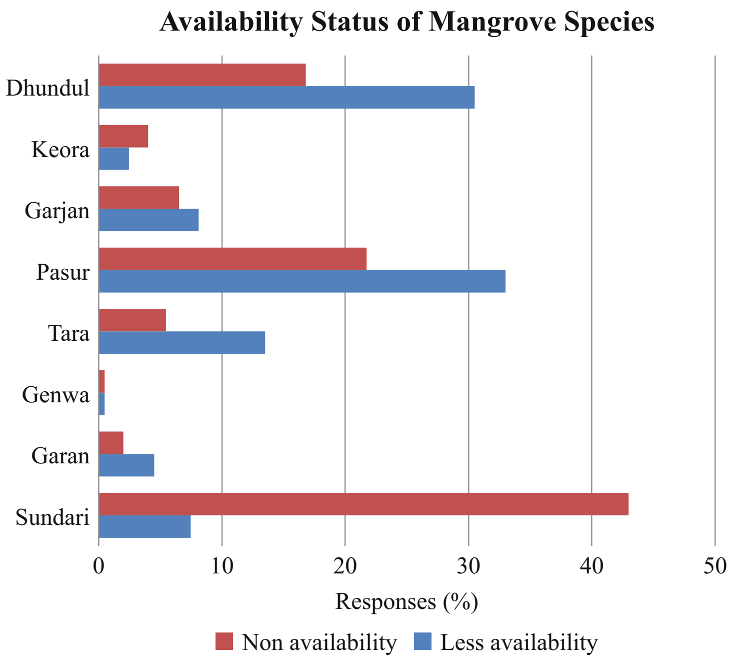


Fig. 16.19 LULC of Gosaba block, 2020

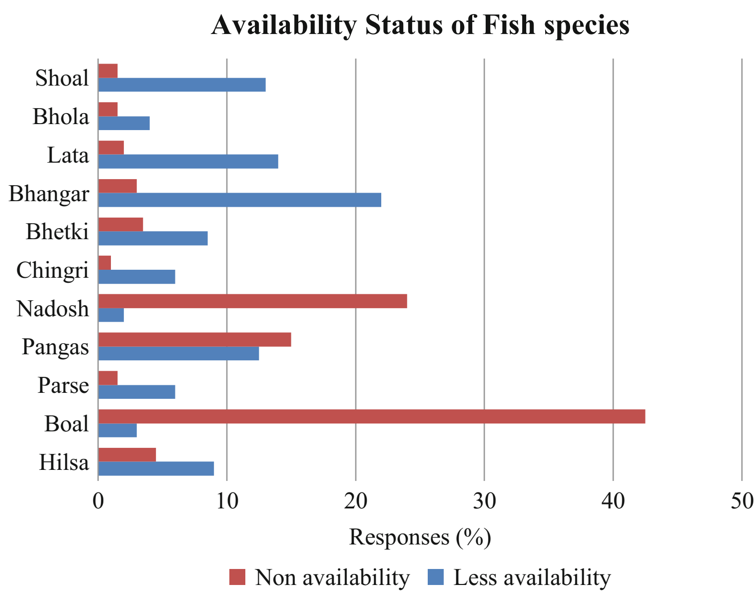
16.5 PRA in Gosaba Block: Analytical Inspection

16.5.1 PRA Methods Employed in Gosaba Block

As the villagers of this block witnessed several natural disasters, their local and traditional knowledge and understanding can be equipped and distributed among their immediate family members and neighbours through practicing the PRA technique. Likely, it was known from them during the discussion that the incoming storm surge was indicated by the sudden rise of humidity and calm river or sudden migration of fish; an upcoming disaster was indicated by the birds chirping in the middle of the day, migration of ants towards inland from their burrows, strange behaviour of fishes in ponds, and many more. All these knowledge and modern warning system along with the management techniques, if communicated in a suitable and participatory way, will be more valuable and applicable in resource management. Some of the PRA tools were implemented in the current effort (Photograph 16.1 and 16.2), like **Focus Group Discussion (FGD)** sessions with six to ten male or female members; **contextual change exercise,village timeline exercise, and livelihood exercise** methods were applied to identify the changes experienced by the respondents over time concerning seven domains (forest cover,



Photograph 16.1 Resource map in a Gram Panchayat



Photograph 16.2 Key informant interview in Gosaba block

climate change, agricultural, built environment, economic and socio-cultural changes, human capital), to understand how people's live and livelihood have changed, and to understand the prime cause of such changes.

16.5.2 *Mangrove Dynamics and Ecological Backlash in Gosaba Block*

The enormous population stress and their revenue-generating behaviour habitually impede the mangroves as well as the biodiversity of the entire Sundarban, and the individual block like Gosaba is no exception. Thus, the ecological backlash by anthropogenic trouble and economic activities has been studied in the Gosaba block on some mangrove and fish species, where the availability status of such species is pointed out (Figs. 16.20 and 16.21). Most respondents report that *Sundari* is the most endangered tree species among all, as it is either less available (7.45%) or not available (43%), while *Dhundul* is the second rarest tree species, as it is either less available (30.50%) or not available (16.80%) at present. Furthermore, *Pasur*, *Tara*, *Garjan*, *Keora*, and *Garan* are the other important tree species, which have also been reported as rare species. Among fish species, *Boal* is the rarest species as it is not available at present (42.50% respondents). The other most threatened fish species are *Nadosh* (non-availability is 24%) and Pangas (non-availability is 15%), and the availability of *Bhangar* is also declining (22% respondents). Moreover, *Hilsa*, *Lata*, and *Shoal* are also reported as less available than before as of the respondents. In fact the inhabited forest-dependent community is also very much aware of the biodiversity loss; there is the need of involvement of them in the development process through PRA with proper planning and support by the government and NGOs.

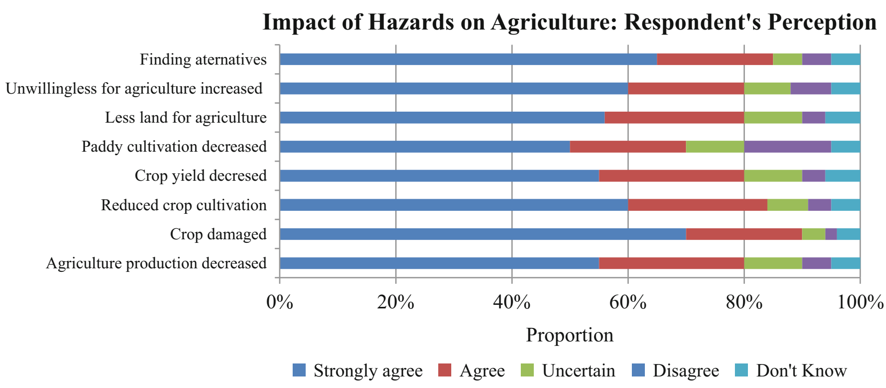


Fig. 16.20 Availability status of mangrove species

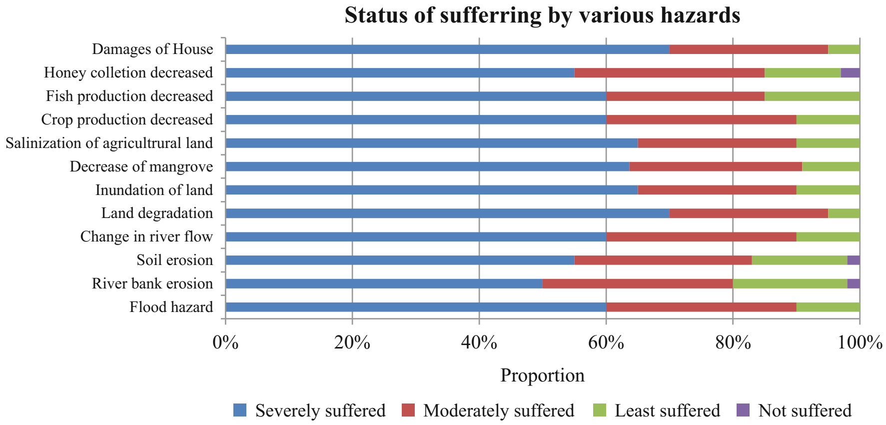


Fig. 16.21 Availability status of fish species
Data source: Primary survey, 2019

16.5.3 Submission of PRA and People's Participation in Gosaba Block

The PRA technique comprises diverse methods and approaches that enable people to express and analyse the realities of their livelihood, and that was very much pertinent in case of Gosaba block and probably in most of the other blocks of Sundarban. With the application of PRA technique, data were collected from the study villages through topical interview, oral trend, and listing methods, and to authenticate the collected data, it was reaffirmed and validated by key point discussion and personal observation. It also provides an alternative way of qualitative than quantitative data collection (Reddy 1999) and analysis (Mukherjee 1997). The forest conservation, disaster management, and sustainable economic practices with the mass involvement and active participation of the inhabitants of Gosaba block were studied by PRA methods and tools, and the table (Table 16.8) prepared on the basis of such is self-explanatory.

16.5.4 Appliance of PRA to Assess the Impacts of Hazards

When Cyclone Aila divested the islands of Sundarban in 2009, or the hitting of Cyclone Bulbul in 2019 and Cyclone Amphan in 2020, many villages of the Gosaba block were suffering by diverse problems due to embankment breakages and damages, inclusion of saline water, and inundation of agricultural land by saline water along with the loss of mangroves in the nearby forest. With the help of PRA technique, some ventures were initiated to practice sustainable resource utilization, like farming in the low productive land, fruit tree plantation, plantation of wood tree,

Table 16.8 Employment of PRA for forest conservation in Gosaba block

People's participatory plan (PPP)	Forest conservation and management	Sustainable agriculture and fishing practices	Disaster management
Implementation and monitoring of PPP through diverse approach, tools, and methods of PRA and RRA (rapid rural appraisal); identification of problem, analysis, decision-making, planning, and evaluation	Understanding of diverse and complex nature of mangrove ecosystem; importance of forest resource conservation; plantation; participatory forest management, agro-forestry, social forestry	Soil testing, soil-oriented crop cultivation, organic farming, vermin compost, climate-resilient agriculture; enhancement of agricultural sustainability	Preparation of risk maps; risk analysis; pre-disaster preparedness; identification of weaker section of community; evacuation plans; disaster-ready programs; use of upstream technology
Application of flow chart and transects	Resource mapping, forest mapping	Use of seasonal calendar, flow chart	Risk zonation mapping, flow chart, social mapping

Source**:** Primary survey, 2019

Table 16.9 Ranking of hazardshazards affecting the Gosaba block

Rank	Hazards	Connections with forest	Impacts
1	Riverbank erosion	Continuous and strong	Long-term impacts on mangroves and livelihood
2	Cyclone	Very intensified, frequent, and very strong	Instant and damaging effect observed on mangroves and life
3	Embankment collapse	Continuous, slow poisoning, and long term	Hamper the life and livelihood continuously with long-term effects
4	Flood	Associated with cyclone and embankment damages and strong long-term effect	Loss of mangroves and land for economic uses affects livelihoods
5	Salinity inclusion	Affect livelihood very much for short- to medium-term effect	Reduction of agricultural production compelled people to convert the land for aquaculture or migrate for wage labour

Source: Primary survey, 2019

vegetable gardening, poultry farming, pond re-excavation to hold rainwater, and small business (rickshaw pooling, tea stall, small shop, etc.). The group and household interviews and key informant interviews were carried out, and the ranking of hazards that are affecting the mangrove forest and livelihood is portrayed here (Table 16.9).

In the search of an alternate livelihood, village ecotourism in this section was introduced, and this could be enhanced with greater facilities with the involvement of the government by enhancing the facilities and training, awakening, and giving loan facilities so that it imparts sustainability support services. The outcomes of the

Table 16.10 Diverse aspects, nature of challenges of hazards, and adaptations

Aspects	Nature and degree	Challenges by cyclone and related hazards
Environment	Impact	Coastal erosion, loss of mangroves, breaching and damages of earthen embankment, coastal erosion, mangrove loss
	Level of impact	Very severe and long term
	Coping style	Building a new embankment, taking government compensations, more inclined to the mangrove forest area
Agriculture	Impact	Inundation of agricultural land, reduction of land for cropping, crop loss, cross disease, increases soil salinity
	Level of impact	Very severe to severe, increasing helplessness, food crisis, malnutrition, disease, increasing poverty
	Coping style	Cultivate salinity-resistant crops, trying to collect salt-tolerant paddy seeds and HYV seeds, cultivate vegetables, migrated, became wage labour, trying for an alternate income generation
Livelihood	Impact	Damages of house, roads, displacement, intrusion of saline water, life risk, loss of fish collection, shortage of drinking water problems, increase poverty
	Level of impact	Very severe to severe, long-term effect
	Coping style	Migration, selling household assets, borrowing money from moneylenders
Health	Impact	Waterborne disease, women and child affected much, fever, cough-like disease, malnutrition
	Level of impact	Very severe to severe, increasing helplessness
	Coping style/adaptation strategies	Dependent of quack doctors or local medical practitioners, rarely treated in hospitals, primary health centres, sub-centres, private clinic, migrated to cities

Source: Perception study during primary survey, 2019

survey of PRA techniques conducted in three Mouzas of three different Gram Panchayats (GPs) about the hazards, vulnerability, challenges, and adaptations are tabulated (Table 16.10) which are self-explanatory.

The perception study of the community of the Gosaba block on various issues of climate change and induced hazards along with their effects on the livelihood and ecological systems is tabulated (Table 16.11), which is very essential to identify the vulnerable groups and to introduce planning and development of the backward region of Sundarbans.

During the practice of PRA, more than 65% respondents strongly agreed and agree with the decrease of paddy and crop cultivation and lessening of crop yield and agricultural production due to the impact of hazards (Fig. 16.22). Moreover, crop damages and less land remain suitable for agriculture, mostly after any sort of hazards makes them vulnerable, and they are becoming unwilling for agriculture and finding alternatives. A very few respondents are unable to relate climate change to agriculture, and thus they replied they don’t uncertainly know, whereas an insignificant amount of respondents disagreed with such facts.

Table 16.11 Livelihood issues affected by climate change-induced condition

Livelihood issues	Cyclone	Flood	Riverbank erosion	Embankment damages	Salinity	Sea level rise	Soil erosion
Agriculture	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Livestock	Yes	Yes	Yes	Yes	Yes	***No***	Yes
Fishing	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Shrimp culture	Yes	Yes	Yes	Yes	Yes	Yes	***No***
Honey collection	Yes	Yes	Yes	Yes	***No***	Yes	***No***

Source: Perception study during primary survey, 2019

Fig. 16.22 Impact of climate-induced hazard on agriculture
Data source: Primary survey, 2019

Various climate change-induced hazards and vulnerability which affect the source of income and livelihood were surveyed and graphed (Fig. 16.23) to understand the status of suffering of the people in Gosaba block.

It reveals that more or less than 60% of the respondents severely suffered, about 20% or more moderately suffered, and the rest of the portions least suffered by various happenings like occurrence of flood hazard, riverbank erosion, changes in river flow, embankment collapse, decrease of mangrove, decrease in fish and honey collection, lessening of crop production, salinization of agricultural land, land inundation and degradation, soil erosion, and damages of houses; only some of the respondents replied that they are not affected by some of the events directly but still suffered a lot and their life has always been at risk.

Fig. 16.23 Status of suffering by climate-induced hazards
Data source: Primary survey, 2019

16.6 Discussion

The livelihood pattern of Sundarban largely depends on the physical environment, because of its homogeneousness and acute nature, but the resource potentiality particularly forest resources is very significant to the inhabitants as most of the economic activity of Sundarban is either associated with the forest or largely depending upon it. In Indian Sundarban, about 70% people are unemployed and about 27% belong to major employment, while about 3% belong to marginal employment. Thereafter, agriculture and fishing become the thrust area to sustain their livelihood, and any sort of damages and exploitation of these sectors by natural hazards poses them to exploit natural forest resources in various ways, and/or they migrated in the search of alternatives. As poverty is the reality in the area, food, shelter, and income-generating openings are the prime concern of the inhabitants of Sundarban. Thus, among the three distinct zones of SBR, i.e. core, buffer, and transitional, people are exploiting forest resources from the buffer zone by their income-generating activities, like TPS collection, collection of crabs and oysters, and apiculture, whereas reclamation of land for economic activities and habitation in the transitional area are the major threats, and thus the forests area degraded. Apart from the conflicts between the inhabitants and forest guards, human-wildlife conflicts are also very common, especially in the blocks close to the forest, like Gosaba. The existence of several overlapping institutions and governing authorities to protect the forest and the development of the inhabitants and their complex interactions make the livelihood more insecure and the situation often getting aggravated by the attack of any cyclone and related hazards.

It was observed in the Gosaba block that with the absence of required earning from a meaningful livelihood, people are often bound to engage themselves in activities like collection of TPS (tiger prawn seeds), fishing in restricted areas, collection of honey in the forest, etc. which exploit the mangrove forest. The enforcement of laws is not effectively tackled with the local people to grapple the problems without including them in the development process, and PRA technique is very much helpful in marinating the mangroves as a national heritage. Forest conservation is not effective and promising without the vigorous contribution of the locals and their awareness, and capacity building should be strengthened with the help of diverse PRA methods. Therefore, substitute, sustainable, and eco-friendly living opportunities need to be initiated and incorporated with the supervision of proper developmental schemes in the view of forest and resource conservation and management by promoting sustainable resource utilization. From the year 2012, with the initiative of some NGOs, *model farmer* or *pilot farmer* concepts- were initiated to adopt organic farming in some parts of the Sundarban. But this method is not successfully incorporated without the application of PRA technique as it helps to understand the suitability of crops, according to their experience and the recent development in the farming system. Thereafter, by this organic farming, farmers of the Gosaba block in the current study villages adopted organic farming system where they cultivated crop in a part of their land and cultivated potato, pumpkin, radish, cauliflower, cabbage, ladies finger, and other vegetables, and it is suitable for the environment as it reduces the negative effect in case of using fertilizer and pesticides and improves the soil health. Highly salt-tolerant mangrove species like *Avicennia marina* is planted in the deforested area where the high influx of salt water penetrates to form a barrier against any disaster and to combat the issues of sea level rise and climate change by scaling down the ominous effects. Such mangrove plantation is useful to stabilize the soil particles; control soil erosion; especially in embankment; and slow down the tidal wave.

Any conservation activity without economic improvement of the inhabited population in the current study area is difficult as the absence of any guaranteed income, low productivity of lands, and lessening of fish catches made the populace more dependent on mangrove forest for resource explosive income options, like collection of tiger prawn and crab, illegal felling of mangroves, collection of non-timber forest, poaching, overgrazing by livestock, etc. Therefore, involving the locals in the conservation process along with the plant activity of saplings using their emotional attachment with the mangroves would become a more fruitful method because lecturing about climate change and/or forest degradation from a scientific perspective can never be an effective and practical solution in such a vulnerable area. Moreover, the inhabitants of Sundarban must switch over to alternative sources of income instead of agriculture and fishing. A new set of income-generating opportunity-based work should be pursued, like prospective agriculture (oil seeds, red chilies, tomato, sunflower, and vegetables), agro-based industries (oil mills, rice mills, etc.), and forest-based industries (honey and beeswax collection, etc.), sustainable tourism, and ecotourism. The salt-tolerant paddy variety and use of HYV seed and biofertilizer should be distributed, and it may be incorporated in the development of agricultural sector so that people are able to reduce the pressure over the mangrove forest area. Introduce the training of the local fishermen community about the eco-friendly practice of fishing. Conservation of the aquatic resources of the area must be strengthened to ensure the source of income for associated people of Sundarban. An environmental monitoring cell should be introduced to implement fishing rules and regulation and to take care of the fishing grounds in ways like banning of some destructive nets, replacement of some nets, rotation of fishing grounds, restriction of trawler routes, banning of night trawling, and maintaining the ecological balance in the aquatic area. The local community must be motivated to conserve their own habitat for their own benefit and from their own will rather than government directives will ensure better management. Therefore, to reconfigure devilment strategies counting neighbouring requirements in a multi-scalar and polycentric manner, interdisciplinary and collaborative approach with the inputs from natural and social scientist should be developed.

16.7 Conclusion

The present attempt is trying to record extensive scrutiny on various forest management and its distortion or deviation along with the associated inhabitant's livelihood which are frequently threatened by climate change-related shocks and stresses, which are adding pressure to the already precarious livelihoods of marginalized people in the Sundarban. The in-depth analysis of mangrove dynamics and livelihood patterns in Sundarban even at the micro level and its adjustment to the changing climate-induced hazards have portrayed some important issues that have been empirically conferred. Howsoever, the study of three distinct villages from three Gram Panchayat of the Gosaba block provides useful insights into the realities of livelihood, activities, and mangrove forest dependency which could be incredibly constructive for maintaining forest health, conserving the forest and wildlife as well as policy framing, implementation and strengthening the involvement of local people and this could be added fruitful with the execution of PRA and geospatial techniques to tease out the diverse issues in such an area where backwardness, remoteness and rich natural resources co-exist and which are frequently threatened by tremendous environmental situations effecting by changing climate. The climatic hazards enhances the vulnerability to the inhabitants who are already suffering from the poverty, massive illiteracy, health hazards, dependent on natural resources, often get displaced, migrated for better wages, and so on and so forth. The increasing economic stress due to the climate change-induced physical vulnerability, which is strong enough to boosting other sort of vulnerability, is totalling the adverse state of affairs and creating pressure to the marginalized, coastal, fringing, and remotely positioned populace of the blocks like Gosaba in Sundarban. Therefore, environmental and socio-economic vulnerability in environmental sectors necessitates instantaneous attention and effective strategy process for the holistic progress in Sundarban, and strengthening the economic base with provision of monetary opening along with the improvement in public transport system is essential for shrinking the effect of adverse climate change. The strengths and opportunities of the forest sectors should be analysed frequently to improve the management status, and more salt-tolerant crop variety, better crop combination, alternative cash crop cultivation, and strengthening the fishing sectors should be introduced to reduce the inclination of forest resource use by the local people. Moreover, adaptation of new technology; continuous assessment and monitoring of forest by geospatial technology; diminishing the threats and weakness of forest sectors; and increasing people's participation through PRA tools and methods are some pillars to be prioritized for the betterment of the Sundarban. Appropriate adaptation strategies along with participatory appraisal by empowering communities with education, employment, technological development, and awareness enhancing can be the best way to address the issue of forest conservation and management and cope up with such climate change and vulnerable situation. Furthermore, education and awareness; healthier transport connectivity to boost the mobility and afford better access; minimizing the poverty and reduction of population pressure on resources; indurate proper embankment alongside the coastal and fringing villages; and disaster risk management are the immediate requirement to uplift the material and communal structure which will definitely work out to cope up with such important issues and events, and such kind of several research outcomes may ameliorate in the planning process to prioritize the adaptation program multiplicity to address the current long-term sustainability issues of Sundarban.

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Part V
Human-Wildlife Conflicts

Chapter 17
Changing Landscape and Escalating Human-Wildlife Conflict: Introspection from a Transboundary Landscape

Prashanti Sharma, Janita Gurung, Kesang Wangchuk, Kabir Uddin, and Nakul Chettri

Abstract The Kangchenjunga Landscape (KL), a transboundary area shared by Bhutan, India, and Nepal, identified human-wildlife as a cross-border issue. Diverse in species and its ecosystem services, this landscape is characterized by the presence of isolated protected areas in proximity to human settlements and agricultural land. Diverse wildlife species (large carnivores, mega-herbivores, omnivores, meso-mammals, and birds) have affected the lives and livelihood of the people in the landscape through crop raids, livestock depredation, and lethal attacks. As a result, a negative attitude towards wildlife that includes retaliatory killings is common in the region leading to a loss of biodiversity and disruption of the ecosystem structure. The landscape is witnessing change due to population growth and development affecting the severity and intensity of conflict in the region. The KL is marked high rates of land modification whose impact, especially around protected area boundaries, resulted to higher occurrences of conflict. Geographic Information System (GIS) mapping in a human-modified landscape, when related with spatial density of conflict, shows a significant positive correlation. Lack of effective connectivity corridors between protected areas and fragmentation due to human development activities has, therefore, significantly affected the rates of human-wildlife conflict in the region. The constant movement of wildlife species through human landscapes across international borders has added complexity to the problem. Hence, addressing the transboundary migration of wildlife and its impact on humans and wildlife is important in tackling human-wildlife conflict.

Keywords Land use change · Human-wildlife interaction · Geospatial analysis · Negative impacts · Eastern Himalaya

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17.1 Introduction

Effective biodiversity conservation requires an understanding of interdisciplinary approach that connects ecological and social factors (Pooley et al. 2014). This challenge becomes important for conservationists while tackling the discord between human welfare and biodiversity conservation, particularly concerning human-wildlife conflict (Peterson et al. 2010). Although human civilization has lived in proximity to wildlife, the severity of their interaction has become increasingly negative, frequent, and widespread, culminating in conflict (Nyhus 2016). Human-wildlife conflict (HWC) is defined as the direct and perceived threat posed by wildlife to human lives and livelihood, health, and property, leading to retaliation through wildlife persecution (Nyhus 2016). The conflict between humans and wildlife negatively affects the social, economic, and cultural lives of affected communities, besides impacting wildlife conservation and the environment (WWF 2005). Encroachment of humans and wildlife into each other's habitat or living space damages ecosystem health, food security, and socioeconomic and psychological well-being of communities. Crop raiding, livestock depredation, property damage, and even loss of human life due to wildlife intrusions in human settlements affect livelihoods and productivity (Lamarque et al. 2009) while also creating negative attitudes towards conservation efforts (Treves et al. 2006). HWC also leads to the retaliatory killing of animals, resulting in biodiversity loss while increasing the risk of zoonotic diseases (Thirgood et al. 2005).

Human interference in wildlife's natural habitat, most importantly, through land use change has led to competition for shared resources, resulting in conflict (Karanth and Kudalkar 2017). Deforestation and forest fragmentation are responsible for the decreased dispersal ability of wildlife in their home ranges, causing a frequent confrontation between human and wildlife, particularly in forest fringes. As human activities have altered almost 70% of all terrestrial ecosystems, a number of species are forced to inhabit such human-dominated and modified landscapes. As a result, wildlife-related conflicts have increased in recent years (Ellis et al. 2013). Human modification of landscapes results to a heterogeneous mosaic of different habitats, both natural and human modified, where both domestic and wild species can persist (Gardner et al. 2009). However, such change increases interaction with wildlife due to readily available foods in the agricultural fields, pastures, and even domesticated animals (Karanth and Ullas 2002; Munguía-Carrara 2020).

Kangchenjunga Landscape (KL) is a complex within one of the 36 Global Biodiversity Hotspots - the Himalaya. These hotspots are regions identified based on high biodiversity, higher proportion of endemic species, higher rate of habitat degradation, and high human pressure (see Mittermeier et al. 2011). In India, the Himalaya, part of Indo-Burma, and Western Ghats have been identified as hotspots. The KL, as part of the Himalaya, has experienced a rapid increase in human demography and economy, leading to significant land use land cover changes, and loss of forests, resulting in modification of terrestrial landscapes (Chettri et al. 2010). Due to drastic changes in the land cover, various types of conflicts ranging from crop-raiding monkeys to frequent interaction with human with tigers and leopards, among others, are now common in most parts of the landscape. Bhutan, a part of the KL, experiences an annual crop loss of up to 25% of total household income due to crop forage by wild animals. The Southern lowland of eastern Nepal is severely affected by HWC through crop raids and property damage caused by elephants (*Elephas maximus*) (Neupane et al. 2017).

Researchers from around the globe have employed various techniques for understanding HWC through questionnaire-based perception studies and spatial analysis of events (Grey et al. 2017; Neelakantan et al. 2019). The Geographic Information System (GIS) has proved a useful tool in identifying and analyzing how HWC varies in time and space (Ruda et al. 2018). Spatial modeling approaches have been used to analyze patterns, quantify damage, examine relationships with habitat use, and spatially predict hotspots in hills and plains of the eastern Himalaya (Kshettry et al. 2017; Naha et al. 2019; Sharma et al. 2020; Chen et al. 2016). Researchers have carried out studies on fragmentation using the landscape fragmentation tool integrated into the GIS environment to assess forest degradation and identify forest core areas (Singh et al. 2017; Shapiro et al. 2016). Likewise, Acharya et al. (2017) examined the role of forest fragmentation as an indicator of HWC for various species in Nepal.

Previous work by Sharma et al. (2020) focused on predicting hotspots of HWC in the KL using secondary literature data and determining a relationship between fragmentation and HWC. In our current study, we aim to use this data to assess the influence of human modification of the terrestrial ecosystem on HWC. A bivariate analysis of landscape modification and HWC will be useful in identifying areas of major concerns and degree of interrelatedness between two variables in the landscape. Since fragmentation in the landscape is related to HWC (Sharma et al. 2020), we classified the landscape based on the extent of fragmentation and delineated the regions most affected by HWC in these classes.

17.2 Study Area

Human-wildlife conflict is an important issue identified by each of the three countries within the KL (Fig. 17.1). Bhutan, India, and Nepal are the three member countries of this transboundary landscape that spans across 25,085.8 sq.km in the Hindu Kush Himalaya (HKH). Some underlying causes for HWC in the KL are habitat fragmentation and the presence of small isolated protected areas in proximity to human settlements and agricultural land. Hence, addressing HWC through an ecosystem-based approach was identified as a key action in the 20-year strategic document (ICIMOD, WCD, GBPNIHESD, RECAST 2017).

The physiography of the Kangchenjunga Landscape includes the Terai-Duar lowlands of the Indo-Gangetic Plains in the southern region, the Sub-Himalayan and Lower Himalayan Ranges up to 3000 m, and the Greater Himalayan Zone and Tibetan Plateau in the northern section. These varied physiographic zones host

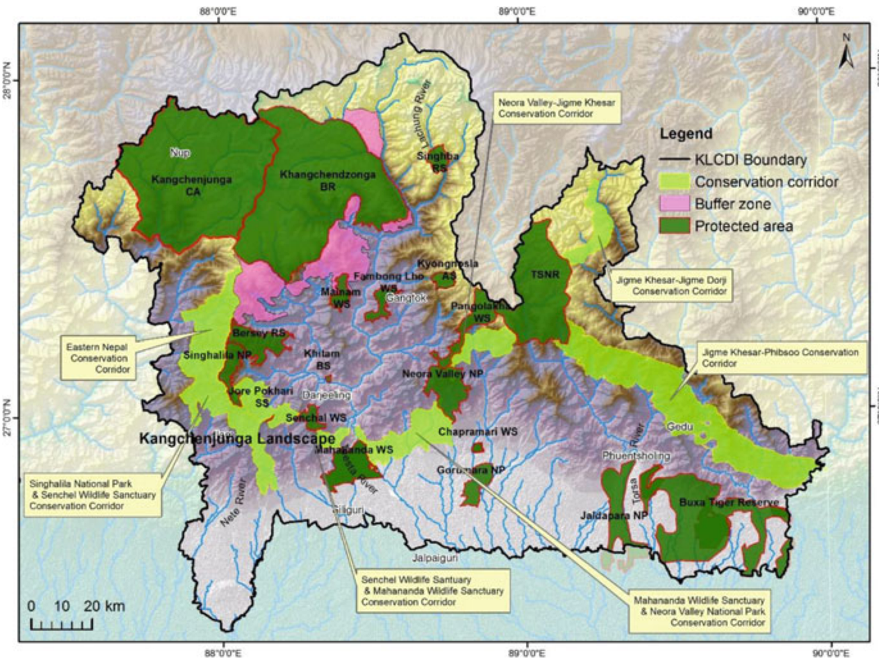

Fig. 17.1 Study area showing Kangchenjunga Landscape with conservation areas along elevational gradient

several ecosystem types – forests, rangelands, wetlands, agroecosystems – that are inhabited by different faunal species, including wildlife such as Bengal tiger (*Panthera tigris*), one-horned rhinoceros (*Rhinoceros unicornis*), and the Asian elephant (*Elephas maximus*) in the lowlands; red panda (*Ailurus fulgens*), common leopard (*Panthera pardus*), and clouded leopard (*Neofelis nebulosa*) in the mid-hills; and snow leopard (*Panthera uncia*) and Himalayan black bear (*Ursus thibetanus*) in the high mountain region. Each of these wildlife species interacts with humans through different interfaces that result in negative (e.g., conflicts, loss of livestock or infrastructure, diseases, etc.) or positive (e.g., wildlife protection, ecosystem services, income generation through wildlife tourism, carbon sequestrations, etc.) effects (ICIMOD, NCD, GBPNIHESD, RECAST 2017; Kandel et al. 2019).

Human-induced development activities along with about seven million people living in the landscape have stressed natural resources in the KL (Kandel et al. 2016). This has mostly influenced the degradation and fragmentation of its forest ecosystems, resulting in subsequent habitat reduction of megafauna such as elephants, giving rise to HWC. Even smaller mammals, such as leopard cat (*Prionailurus bengalensis*) and Himalayan yellow-throated marten (*Martes flavigula*), predate livestock and poultry, whereas wild boar (*Sus scrofa*), barking deer (*Muntiacus muntjak*), monkeys (*Macaca mulatta*), porcupines (*Hystrix* spp.), and birds like peafowls (*Pavo cristatus*) are known to forage crops (ICIMOD, NCD, GBPNIHESD, RECAST 2017).

17.3 Database and Methodology

17.3.1 Data Collection

17.3.1.1 HWC Incidence Data Compilation

The HWC incidents data of Sharma et al. (2020) was used in this chapter. The incident locations in the study area were compiled using secondary literature sources. This location information was geocoded in Google Earth to derive its latitude-longitude coordinates. In order to derive the locations of the incidents of HWC, 56 news articles, journals, and reports were referred to include HWC with all available species for the last 19 years (2000–2019) across the landscape. Additionally, we also used Global Positioning System (GPS) information of HWC occurrence, collected by the Nature Conservation Division (NCD) in Bhutan. We collated all additional HWC location points available for the landscape and added 250 additional HWC coordinates in Sharma et al. (2020). We identified a total of 492 points of HWC occurrence points across the entire landscape.

17.3.1.2 Global Human Modification of Terrestrial Systems (HMOD)

To measure the degree of human-induced modification in the landscape, we used a Global Human Modification of Terrestrial Systems (HMOD). The dataset was available as a geographic information system (GIS) raster at 1 km spatial resolution. The HMOD reflects the proportion of human modification of terrestrial lands and is expressed through continuous 0–1 metric. Physical extents of 13 anthropogenic stressors using spatially explicit global dataset along with their estimated impacts with the median year of 2016 were used to model the HMOD dataset (Theobald et al. 2020). The spatial data is accessible to download from here.

17.3.1.3 Land Use Land Cover (LULC) Map

We used the land use land cover (LULC) map from Sharma et al. (2020), covering the study area of KL. The map was produced at 30 m spatial resolution using atmospherically corrected level 2 thematic mapper (TM) satellite images acquired on demand. The authors developed a land cover classification with 11 classes, following harmonized and hierarchical system based on Di Gregorio (2005). Object-based image analysis (OBIA) was employed on satellite images to derive land classification using eCognition Developer software. Additional data such as the normalized difference snow and ice index (NDSII), normalized difference vegetation index (NDVI), and a land-water mask were also incorporated in the classification process. This data, in raster form, is freely available for download from the ICIMOD's Regional Database System (Fig. 17.2)

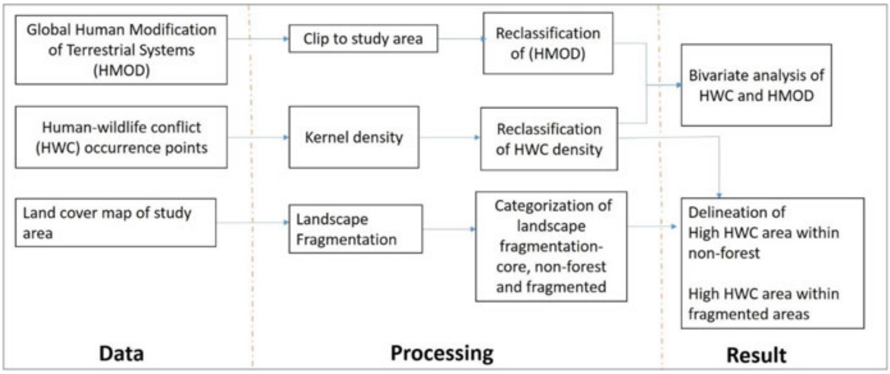

Fig. 17.2 Schematic flowchart showing the methodological approach used in the study

17.3.2 Processing

17.3.2.1 Kernel Density

The latitude and longitude coordinates of all points relating to HWC incidents were converted into a shapefile, a GIS file format. These points were used in ArcGIS 10.8.1 to calculate the density of HWC occurrence across the landscape. We used the kernel density (KDE) tool, available through ArcGIS's Spatial Analyst toolbox, to produce a smooth density surface of occurrence points over the study area. The tool calculates a value per area unit from an event location using a kernel function that fits a smoothly tapered surface (Bowman and Azzalini 1997). KDE is built on the principle of a heat map that produces continuous raster representing core areas (kernels) and neighborhood pixels (Bonnier et al. 2019). The tool allows control of the search radius of the kernels, affecting the degree of smoothing (Krisp and Špatenková 2010). GIS-based KDE is most commonly used to analyze the intensity of risk events, define hotspots, and visualize data (Poulos 2010; Loo et al. 2011; Parajuli et al. 2020; Krisp and Špatenková 2010). We used default search radius computing using a spatial variant of Silverman's Rule of Thumb, which is robust to spatial outliers. Cell area of density map was set to 5 sq.km to match the spatial resolution of other datasets. The KDE tool produced density values were reclassified into class 1 (low density of HWC) to 5 (high density of HWC) based on natural jenks classification.

17.3.2.2 Reclassifying HMOD Data

The global data on HMOD was downloaded and clipped to the study area extent in ArcGIS 10.8.1. The dataset was resampled to 5 sq.km spatial resolution using the nearest neighbor resampling technique. The values were reclassified to five classes ranging from 1 (low modification) to 5 (high modification) using natural jenks classification. The areas with high HMOD, represented by classes 4 and 5, were extracted.

We analyzed the relationship between the density of HWC calculated through kernel density and HMOD through regression statistics and visualized it through a bivariate map. Correlation between values of HWC density and HMOD at each grid location was measured using Pearson's correlation coefficient, and the ANOVA test was conducted to test the significance of correlation.

17.3.2.3 Landscape Fragmentation

The study also analyzed the fragmentation of forests in the Kangchenjunga Landscape by using the Landscape Fragmentation Tool (LFT v2.0). The tool uses a land cover map in binary form – forest and non-forest – to classify the landscape into various categories of fragmentation. The land cover map was, therefore, reclassified to 1 (forest: broadleaved forests, needle-leaved forests, and mixed forests) and 2 (non-forest areas: croplands, built-up areas, grassland, and snow and ice) and used as input to LFT tool integrated in ArcToolbox.

The LFT tool yields four main classes – core, edge, perforated, and patch – based on an edge width specified by user (Fig. 17.3). The edge was assumed to be 100 m which is the distance up till which the degradation effect of the land cover of interest (i.e., forest) is maximum. The core is forest pixels that are not degraded by "edge

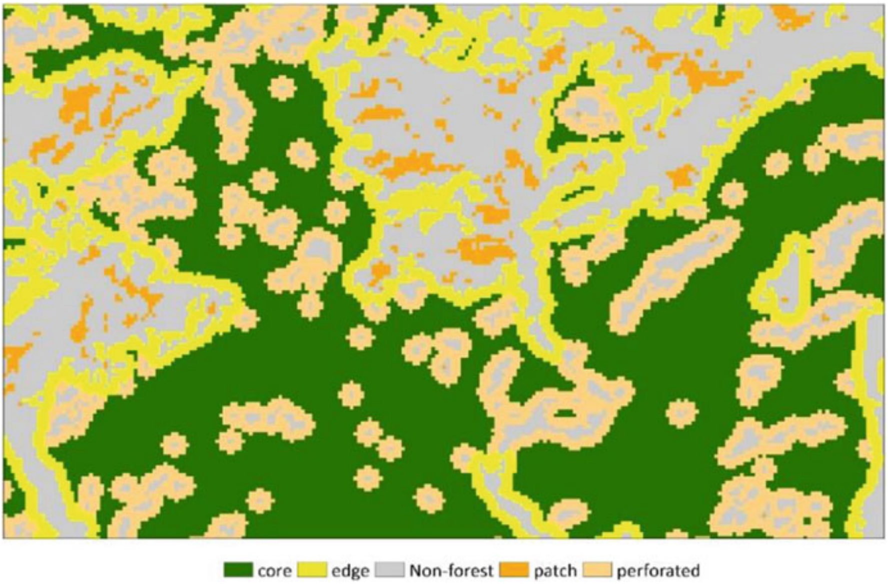

Fig. 17.3 Diagrammatic representation of forest fragmentation classes

effects." The core is subdivided based on thresholds for minimum viable forest patch sizes – small core (<101 ha), medium (101–202 ha), and large (>202 ha). Cells along the edge of an interior gap in a forest that is deteriorated due to edge effect are termed perforated, and patches relate to small non-connected fragments of the forest completely degraded by the edge (Vogt et al. 2007) (Fig. 17.3).

Edge comprises the outer peripheries of forest bordering large non-forest, which could be encroaching field or pasture (Shapiro et al. 2016). Perforated represents the inner edge along small holes within the cores, and patches are completely isolated forest fragments. Thus edge, perforated, and patch have been grouped to indicate possible degradation resulting due to forest fragmentation, whereas three types of cores depicting intact forest have been grouped as one. The landscape fragmentation layer used a 5 sq.km fishnet to derive the percentage of area covered by each fragmentation class – core and fragmented and non-forest within each grid.

The landscape was divided into three distinct elevation zones to analyze the fragmentation in each zone (Sharma et al. 2020). The lower elevation (<1000 masl), mainly covering the Terai-Duar Savanna and grassland, forms the transboundary habitat of mega-herbivores, especially elephants. This region is characterized by the cross-border migratory movement of these species through non-forested or degraded habitats, leading to conflict with humans. Elevation 1000–3550 masl in the landscape experiences rather localized form of HWC caused due to animals such as leopards, bears, and even porcupine and peafowl. The smaller habitat range of these species and proximity of their habitat to communities living in forest fringes results in conflict. The areas of the landscape with elevation 3550–8586 masl have high mountains with very little interaction of human and wildlife.

17.4 Results

17.4.1 Kernel Density of HWC

Kernel density of HWC occurrence points revealed density values from 0 to 0.12 points per square meters at 5 sq.km grid level. Table 17.1 presents the reclassification of the density values into five classes from low to very high and their respective percentage of area covered. Approximately 30% of the total land area in the Kangchenjunga Landscape is predicted to be under a moderate to a very high density of HWC.

17.4.2 Status of HMOD in the Landscape

The landscape is diverse in terms of landscape modification (HMOD), as the value range from 0.01 (lowest) to 0.83 (highest). The range, reclassified into five distinct categories, revealed 50% of the total area in the Kangchenjunga Landscape had undergone moderate to very high modification through the years (Table 17.1).

Table 17.1 Reclassification of the density values into five classes from low to very high and their respective percentage of area covered

Value and type		Density of HWC		Landscape modification (HMOD)	
Reclassified value	Class type	Range	Percentage of the total area	Range	Percentage of the total area
1	Very low	0–0.02	46.0	0–0.13	29.1
2	Low	0.02–0.04	24.2	0.13–0.29	21.2
3	Moderate	0.04–0.07	17.0	0.29–0.46	21.9
4	High	0.07–0.09	10.5	0.46–0.64	17.1
5	Very high	0.09–0.12	2.3	0.64–0.83	10.8

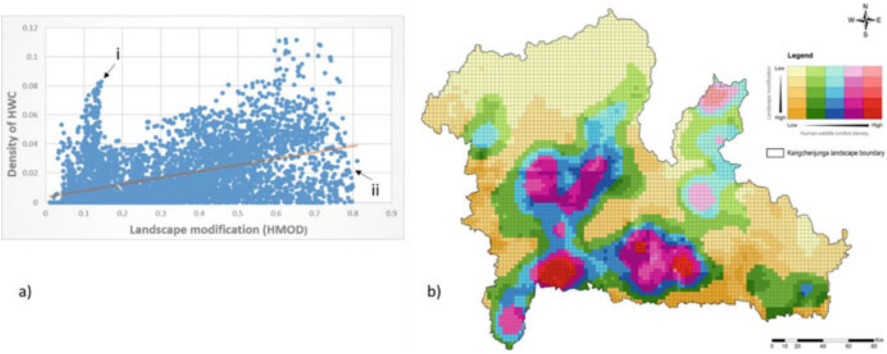

Fig. 17.4 Relationship between human-wildlife conflict density (HWC) and landscape modification (HMOD) represented by (**a**) scatterplot and (**b**) bivariate map

17.4.3 Relationship Between HWC and HMOD

Correlation between values of HWC density and HMOD revealed that the variables are positively related (Pearson's correlation of coefficient r = 0.45, $p < 0.01$) (Fig. 17.4a). This means that human-wildlife conflict density is higher in areas of higher human modification and vice versa. The coefficient value did not reveal a very strong correlation between the two factors, as the values were rather scattered. The scatterplot anomalies are seen in the form of (i) sudden spike and (ii) trough, affecting the direct positive correlation between variables.

A bivariate map displaying the geographic relationship between the two variables over the study area revealed a mixed pattern (Fig. 17.4b). The central and southern regions of the landscape show high intensity of HWC undergoing high landscape modification rates. HWC in the northeastern parts of the landscape were moderately high, though these areas are least affected by human land modification. These areas are represented as spikes (i) in Fig. 17.4(a). The Western and southern-western parts of the landscape were high in human modification but low in HWC density, represented by (ii) in Fig. 17.4a. The northernmost parts of the KL were characterized by very low HWC as well as human-induced landscape modification.

17.4.4 Landscape Fragmentation Concerning HWC

Landscape fragmentation map, generated using the LFT tool, was used to calculate the area of each class. The highest percentage of the KL is covered by non-forest, followed by core forest. Perforated, edge, and patch indicating fragmented areas together constituted 20% of the landscape (Table 17.2).

Three separate maps were produced, showcasing the presence of core, fragmented, and non-forest areas in each grid using the percentage value ranging from lowest to highest (Fig. 17.5). Since HWC events generally occur within the non-forest area, such as in proximity to roads, settlements, and tea gardens, grids with a percentage of non-forest pixels greater than 60% were extracted to represent "non-forest areas" in the landscape. Fragmented areas such as the edge of the forest, perforated regions, and isolated forest patches are more prone to HWC than the core forest. Therefore, grids containing greater than 40% fragmented pixels were extracted to be termed as "highly fragmented areas."

Areas of moderate to very high HWC falling within non-forest and fragmented areas of the landscape were extracted. It was found that the south-central and southwestern parts of the landscape depicted moderate to very high HWC density within the non-forest type. Some areas in the northeast KL were part of this category. Approximately 11% of the total land area in KL presented this combination of factors. In terms of elevation, these areas are mostly present in less than 1000 masl. However, few areas at an elevation greater than 3550 masl were also delineated (Fig. 17.6).

Areas high in fragmentation along with moderate to a very high density of HWC were found in central most of the landscape. These regions mostly covered elevation 1000–3550 masl and represented hilly regions of the landscape. This combination of HWC and fragmentation close to protected areas and conservation corridors within the landscape covered 9% of the total landscape.

Table 17.2 Forest fragmentation classes in the landscape and their respective percentage of area covered

Class	Percentage of area
Non-forest	53.3
Core	27.1
Perforated	8.8
Edge	8.4
Patch	8.2

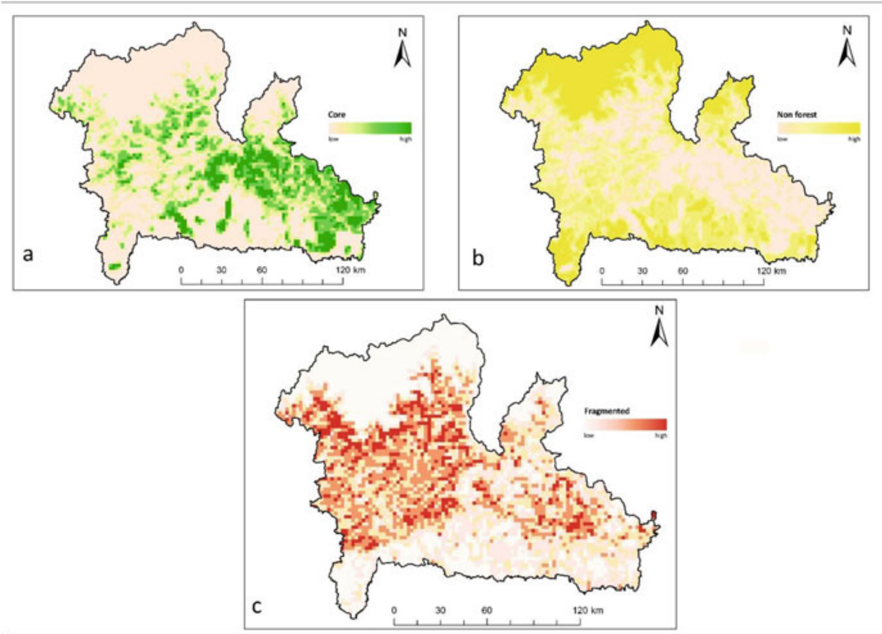

Fig. 17.5 Maps showing forest fragmentation classes in the landscape from low to high: (**a**) core forest, (**b**) non-forest, (**c**) fragmented

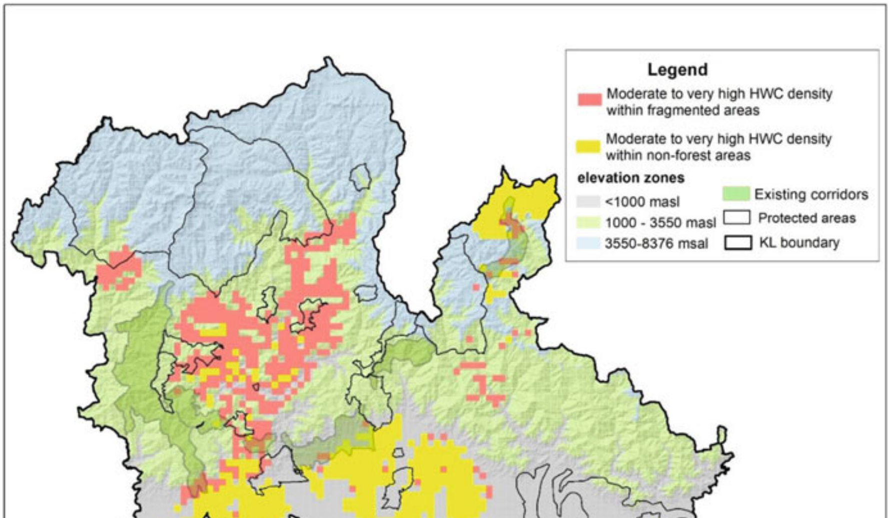

Fig. 17.6 Map showing areas with moderate to high density of human-wildlife conflict in fragmented areas in various elevational zones along conservation areas

17.5 Discussion

The density of human-wildlife conflict is visualized to be higher in the central and southern part of the landscape, constituting North Bengal and Sikkim regions in India. Similar trend was also observed in the northeastern part comprising Samtse, Haa, and Paro districts in Bhutan. Terai and Duars regions of North Bengal experience conflict with mammals, especially Asiatic elephants, tigers, common leopard, and Indian bison. Around 98 human casualties have been reported due to attack by these three species in North Bengal alone between the years 2009 and 2014 (Chakraborty 2015). In the hilly state of Sikkim in the Indian part of KL, villages within and along the forest fringes experience crop raids by monkeys, wild boars, Asiatic bears, and porcupines (Rai et al. 2012).

On the other hand, parts of KL in Bhutan reported predation of more than one thousand livestock by large carnivores during the years 2003–2005 (Wangchuk et al. 2018). Through a comparative study of HWC in various districts of Bhutan, Sangay and Vernes (2008) concluded Paro and Haa to be among less affected districts; its density has certainly increased over the last years, particularly in the buffer of Jigme Khesar Strict Nature Reserve (Wangchuk et al. 2018). Crop loss and livestock depredation are major concerns in the hilly regions of the landscape, while property damage, attacks on human, and crop raids are more common in low-lying belts. The western part of KL did not report high density of HWC, except from the lower belt where elephants are main species at conflict (Koirala et al. 2016). This could possibly be because of a low number of cases reported from this region in news and secondary sources resulting in the unavailability of data points. The result from our study also showed northwestern KL experiences a moderate density of HWC as animals like snow leopard, wild dogs, and Asiatic black bear prey on livestock grazing in pastures or lifted them from corrals (Sherchan and Bhandari 2017).

It is to be noted that HWC is a two-way interaction and the losses are reported from both sides. In the north Bengal alone, in an average, six elephants are killed annually either through retaliatory killing or by accidents in the railway tracts (Roy et al. 2009). The recent review from the landscape indicates that about 400 people and 150 animals have been reported as victim of the interaction (ICIMOD's unpublished report). These figures are conservative as most of the cases are either not reported or documented.

However, HWC is frequent in the areas with high human modification rates that constantly alter largely through agriculture intensification, livestock rearing, and developmental activities such as railways and road constructions. Communities living within and along the fringes of forests or protected areas experience varied forms of conflict that includes animals such as wild boars and porcupines, foraging small farmlands (Rai et al. 2012; Sunar et al. 2012). Wild animals have also been known to attack local communities during the collection of firewood, wild edibles, and medicinal plants from nearby forests. Increasing human interventions in significantly fragile ecosystems have caused severe changes in human-wildlife interaction. The construction of railway tracks and roads has fragmented habitats and causes recurrent conflict between large mammals, especially elephants and humans (Roy et al. 2009). Overexploitation of fuelwood and fodder is responsible for clearing more than half the forest in this region (Shrestha et al. 2018) and replacing natural forests with terraced agriculture between 1000 and 2000 meters (Theobald et al. 2020). Human and wildlife interaction in this rapidly transforming landscape can increase the frequency of conflict for shared resources and lead to a biodiversity crisis (Munguía-Carrara 2020). Hence, it is important to limit the rate of modification in the terrestrial landscape by humans, especially in ecologically sensitive zone like the KL.

Environmental and anthropogenic disturbances are among the major factors responsible for HWC, with distance to roads explaining most of HWC in the landscape (Sharma et al. 2020). Highways, roads, and even small footpaths lead to human interference and increase the interaction of humans and wildlife (Mann et al. 2019; Roy and Sukumar 2017). Areas near to roads (at distances less than 5 km) have been studied to possess higher probability of HWC in the region (Sharma et al. 2020). Such trends are relevant as development-induced forest damage reduces the size of the habitat of many megafaunas. Thus, the Terai and lowland areas in the landscape have become more prone to HWC, similar to those reported by Naha et al. (2018, 2019). HWC highly escalates due to habitat loss and fragmentation. Results suggest the high proportion of the landscape affected by high to moderate HWC within fragmented area which lies mainly between elevation 1000 and 3550 masl. Species such as common leopard and Asiatic black bear common to this elevation zone are associated with attacks in highly fragmented and heterogeneous habitats (Acharya et al. 2017). On the other hand, elevation lower than 1000 masl, forming important transboundary habitat of animals such as elephants and rhinoceros, reported most HWC taking place within non-forested regions. Elephant habitat has been substantially altered through the conversion of forest land into agricultural lands, settlements, and tea plantations, which has affected the migratory routes and the foraging areas of these megafauna like elephants (Singh et al. 2019). Elephants migrate from the northeastern part of India covering the state of Assam and northern parts of the state of West Bengal to the Kingdom of Bhutan and then to Nepal. As part of their migratory course, these mammals make their way up to the Koshi Tappu Wildlife Reserve in eastern Nepal (Choudhury 1999a, b). The protected areas in this entire zone are relatively isolated, lacking connectivity corridors with the presence of non-forested entities and a high human population (Roy and Sukumar 2017). Even at the higher elevation of 3550 masl, high levels of HWC are found in conjunction with high rates of forest fragmentation as well as high non-forest presence – mainly agricultural land and pastures.

Hotspots of human-wildlife conflict vary across the KL. About 19% of the site in the landscape is under the high HWC risk zone (Sharma et al. 2020). Most of the conflict areas in the high-risk zone are at lower elevations. They are related to large mammals such as elephants, tigers, and gaurs, indicating that large mammals could be most damaging to crops, livestock, and humans (Holland et al. 2018). These areas were previously extensive habitats for such large mammals in northern Bengal and eastern Nepal and are part of the movement route for elephants (Choudhury

1999a, b, 2002; Joshi et al. 2016). Modernization and development activities have transformed these habitats and migratory routes into modern amenities such as railway tracks, roads, settlements, etc., confining some wildlife to patches of protected areas (Mallick 2019). Several authors have reported such undesirable development (Roy and Sukumar 2017; Dasgupta and Ghosh 2015; Bashir et al. 2018; Naha et al. 2018, 2019).

While HWC is on the rise, conservation interventions have increased wildlife populations even as their habitats are degraded. The degraded habitats are generally characterized by isolated and small protected areas that are separated from each other, which are not big enough for large mammals such as elephants and tigers (Gurung et al. 2019; Talukdar et al. 2019). The trend of increasing wildlife population and degrading habitats shall only increase HWC soon. During the last decade, research on species' responses to different habitat loss and fragmentation suggests that appropriately sized variety landscapes for wild species should maintain at least 40% of forest cover with ~10% as a large forest patch (Arroyo-Rodríguez et al. 2020). In this regard, ~27% of total area in the KL is core forest, while the rest of the region is divided between non-forest and fragmented habitats, yet there are concerning incidences and severity of wildlife-related conflict. This indicates a necessity for a higher percentage of forest core in this type of tropical ecosystem that is ecologically sensitive and constantly modified by human activities to allow human-wildlife coexistence.

17.6 Conclusion

Human-Wildlife Conflict (HWC) in the Kangchenjunga Landscape is unevenly distributed across the landscape, with high density around the central and southern part. Human modification rates in the landscape are as high as 83% and are positively correlated with HWC density. The interaction and losses are from both sides with increasing number of animal fatalities but hardly reported or documented. The landscape comprises of 27% core or intact forested region and the remaining areas as non-forest, edge, patch, and perforated regions comprising of areas most affected by HWC. Lower elevations of the landscape experience conflict majorly within non-forest areas, whereas the mid-elevation ranges area is affected by HWC within fragmented habitats. HWC conflict within fragmented areas and non-forest areas is closer to the protected areas and is mostly isolated. Few existing biological corridors seem to have very little influence in controlling HWC in the area. Hence, as a part of the holistic approach to tackling HWC in the Kangchenjunga Landscape, a few authors (Mallick 2012; Dhakal and Thapa 2019) suggested the need to identify new corridors in the landscape and connect the forests of Jhapa and Darjeeling and Jalpaiguri forest divisions. Restoration of fragmented forest patches between and within affected countries, by constructing a minimum of 1000 km^2 of suitable habitat, has been recommended to mitigate HWC effectively (Roy 2015). To tackle fragmentation and rate of human modification of landscape affecting at the transboundary scale, it is important for a regional level of cooperation and countries of the three landscapes to develop common strategies. This would in turn aid in addressing the HWC issues that are cross-border in nature.

The need to foster synergies between countries to develop and implement better strategies to tackle HWC requires a transboundary approach. A transborder cooperation program as such could build prospects for human-wildlife coexistence by encouraging countries to develop collective actions towards conservation and development. Improved legislative provisions and increased awareness among user groups would, hence, aid effective and informed decision-making by communities and stakeholders.

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Chapter 18
Issues of Biodiversity Conservation and Conflict in Gorumara National Park, West Bengal, India

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Abstract Gorumara National Park (GNP) in Eastern India is a vastly diverse ecosystem with various habitats and therefore has high floral and faunal diversity. It is a small national park with only 80 sq. km. and is a unique habitat of one-horned rhino (*Rhinoceros unicornis*) and many scheduled species of conservation importance. We made a meagre effort in qualitative and quantitative estimation of ecological impacts of road expansion on the forest buffer zones. In the area demarcated for felling, we identified 86 floral species (29 trees; 55 herbs, shrubs and woody climbers; 3 pteridophytes) including 4 endangered species. 24 species from the buffer zone were of ethnobotanical importance. Carbon emission due to tree felling was 6812 tons from the felled buffer zone of GNP. As habitat fragmentation is one of the causes behind rise in human-wildlife conflicts, we found out that ex gratia relief for animal depredation paid by the forest department (FD) increased almost 32.8 times in the last 10 years at GNP and its fringes. Collected data also showed an annual average of 239 wildlife deaths on the national highway passing through the park's periphery. Thus our survey revealed that there is plenty of scope of extension of home ranges of various endangered wildlife species and reconstruction of corridors of long ranging animals. Developmental activities like road widening in the eastern side impact negatively on the conservation needs of GNP. Such a huge carbon emission from the felled area needs special attention from the perspective of climate change. We suggest proper utilization and widening of an existing alternate route away from GNP, stricter restrictions in vehicular movements, noise and speed following National Wildlife Action Plan guidelines, plantations involving only native species and a participatory approach in conservation of this ecologically sensitive landscape.

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18.1 Introduction

It is a well-known fact that anthropogenic activities such as deforestation and land use change for agriculture are largely responsible for loss of biodiversity. 70% of leftover forests lying within 1 km of the forests' periphery face the deteriorating consequences of fragmentation (Haddad et al. 2015). Habitat loss and formation of small habitat patches as a result of 'fragmentation per se' have a negative effect on biodiversity (Fahrig 2003). Protection of habitats is the most important factor for biodiversity conservation (Filho et al. 2021). Competitive abilities and dependency of a species on fragmented habitats will determine the negative or positive effects on biological diversity (Chetcuti et al. 2020).

In this context, we took a small effort to enumerate the effects of fragmentation on a wildlife habitat. Our study location is positioned in the Indian state of West Bengal whose uniqueness lies in its highest degree of ecological diversity due to the gracious presence of Himalayas in the north, Chota Nagpur Plateau in the east and Bay of Bengal in the south. The Ganges criss-crosses it making the land fertile. Sub-Himalayan region of the state is blessed with species-rich forests of Duars with a range of protected area networks (PAN): Gorumara National Park (GNP), Buxa Tiger Reserve, Chapramari Wildlife Sanctuary, Neora Valley National Park and Jaldapara National Park. This wildlife sanctuary (WLS) and national park (NP) is a biodiversity hotspot region comprising of an enriched forest area with innumerable flora and fauna that remained unaltered over years. Previous studies reported a total of 595 angiosperm species from GNP which resulted in an incredibly high diversity index value (Shannon's H = 6.386) and species evenness values ranging from 0.92 to 0.96 depicting almost even distribution of species within the park (Ghosh 2012). The management plan of GNP stated that the FD could identify 326 plant species (tree species, 158; herbs, 35; shrubs, 77; grasses, 32; climbers, 15; and orchids, 9). Also, sizeable area of GNP is covered with bamboo brakes (Anonymous 2007). Sal (*Shorea robusta*) is a very common and ecologically significant tree species in these forests that is valued by the people. Through widespread field surveys inside GNP, Kumar and Ranjan (2020) counted 350 taxa under 260 genera and 90 families of angiosperms along with 50 palatable species exploited by the locals and tribals.

However, there were no reports on the effects of developmental activities like road expansion at the chosen eco-sensitive area. Thus the present study is significant as it has a focus on probable impacts on the ecological structure and functions as well as biodiversity due to indiscriminate felling (Fig. 18.2) of trees on both sides of the road passing through the buffer zone of GNP from Lataguri to Chalsa, the two small towns in the district of Jalpaiguri (from 26° 43′ 11.7″ N and 88° 46′ 07.43″ E at an Alt -97 m to 26° 43′ 50.55″ N and 88° 46′ 34.58″ E, Alt -96 m). This road passes touching GNP in its eastern side from 26° 44′ 47.36″ N and 88° 46′ 45.74″ E to 26° 47′ 40.84″ N and 88° 47′ 54.10″ E with an average altitude of 101 m. The felling was undertaken for the purpose of road expansion owing to the construction of a flyover in the vicinity of the park. Though the national park area is in the eastern side of the road, the western side of the road corresponding to the stretch of GNP had a luxuriant forest cover with similar ecological characteristics of GNP. As forest buffer zones are extensions of forest core zones, floral and faunal diversities in the buffer area are mirror reflections of that found in the interior of the forest. Hence management of buffer areas should be given adequate prominence in wildlife conservation.

Our research objectives were as follows:

(a) To estimate qualitatively the floral diversity in the buffer zone of GNP (where tree felling took place).
(b) To estimate quantitatively the amount of carbon emission from the felling process.
(c) To study the ethnobotany of the floral species found in the buffer zone of GNP.
(d) To explore the present consequences and predict the probable impacts of road widening from field observations.

18.2 Description of Study Site

Since 1895 GNP was initially a reserve forest that was announced as Gorumara Game Sanctuary afterwards in 1949. In 1994 it was declared as Gorumara Wildlife Sanctuary as per Wild Life (Protection) Act of 1972 with an area of 79.99 sq. km. It was acknowledged as the best National Park and Wildlife Sanctuary in India by the Ministry of Environment, Forest and Climate Change (MoEF&CC) for the year 2009. Lataguri is situated 26° 43′ 15.40″ N and 88° 46′ 05.98″ E and is the entry point of GNP. GNP is situated within 26°47′12.5″ N to 26°43′25.6″ N and longitude 88°52′4.2″ E to 88°47′7.3″ E. Currently the area of the national park is 79.84 sq. km.

The area falls in the Indo-Malaya ecozone. GNP lies in the biogeographical zone 7B Lower Gangetic Plain (Rodgers and Panwar 1988). The distinct biomes corresponding to the ecozone are (a) Terai-Duar savanna and grasslands of the tropical and subtropical grasslands, savannas and shrubland biome and (b) Lower Gangetic plains moist deciduous forests of the tropical and subtropical moist broadleaf forests biome (Anonymous 2007). According to Champion and Seth's (1968) classification, the forest type of GNP is the North Indian moist tropical forest. Again, as per the Directorate of Forests (West Bengal), the vegetation distribution in various compartments of GNP is as follows: Riverine forests - North Dry Deciduous Seral Sal Khair Sissoo Association (Tondu - 1,2,3,4a,4b and Selkapara - Ib), Sal forests - Eastern Bhabar Sal and Eastern Terai Sal (Gorumara, South Indong 1,2,3 and Bhogolmardi), Wet Mixed forests – SubHimalayan Secondary Wet Mixed Forests (Barahati - 1,3, Central - 1, Medlajhora - 1, Dhupjhora - Ib, 2 and Kakurjhora - 2) and Savannah Forests & Lower Alluvial Savannah - Sal Savannah (Jaldhaka - Ib and Dhupjhora -la,lb.,lc) (Anonymous 2007). Thus, GNP can be designated as a biome, a combination of multiple ecosystems with diversified habitats. GNP has only 10% (18.41 sq. km) of its total area covered by grassland (Sanyal et al. 2013). The terrain of GNP is differentiated into a distinct plateau and plain areas. The soil profile of the area is of alluvial and Bhabar formations. Average annual rainfall of the NP is more than 382 cm (Anonymous 2007).

Situated at the Eastern Himalayan foothills in the Duars region, GNP has rich biological diversity. The major economic activity of people of this locality revolves around ecotourism industry around GNP. Gorumara NP is famous for natural population of Asiatic one-horned rhinoceros (*Rhinoceros unicornis*), Asian elephant (*Elephas maximus*), gaur (*Bos gaurus*), etc. Gorumara grasslands are well suited for the Asiatic one-horned rhinos though limited pasture and water availability turned them aggressive in the driest months (Bhattacharya and Chakraborty 2016).

It has approximately 48 mammal species (carnivores and herbivores), 193 bird species, 22 reptile species including 7 turtle species, 40 fish species and various other macro- and microfauna (Anonymous 2007). During the fieldwork, many important animal species included in the Schedule I were spotted.

Schedule I mammalian species found in this region are (Mandal 2007) as follows:

(i) Greater one-horned rhinoceros (*Rhinoceros unicornis*).
(ii) Asian elephant (*Elephas maximus*).
(iii) Gaur (*Bos gaurus*).
(iv) Tiger (*Panthera tigris tigris*).
(v) Leopard (*Panthera pardus*).
(vi) Malayan giant squirrel (*Ratufa bicolor*).

Schedule I reptile species listed in IUCN's 'vulnerable' category are as follows:

(i) Reticulated python (*Malayopython reticulatus*).
(ii) King cobra (*Ophiophagus hannah*).

128 avifaunal taxa belonging to 49 families that were observed in Gorumara and Jaldapara National Park included vulnerable and near-threatened species. Disturbance owing to intense flow of traffic on NH-31 perturbed the normal activities of birds in the nearby reserve where the understory plant species were mainly favoured for nesting (Dubey et al. 2015). Butterfly species like Bicolor Cupid (*Shijimia moorei*) and Malayan Nawab (*Charaxes moori*) are Schedule I species of the Wild Life (Protection) Act of 1972. A species named the witch (*Araotes lapithis lapithis*) reported from this NP is also included in Schedule II of the above Act. 314 butterfly species that were recorded during an inventory exercise were documented in the shape of a book (Ghatak and Roy 2013).

18.3 Methodology

The study of issues regarding biodiversity conservation in the study area included not only the study of flora and fauna with respect to qualitative and/or quantitative enumeration but also the study of ecosystems and habitat characteristics of which they were a part.

18.3.1 Field Study

In the disturbed area (where trees were felled), random samples were taken to study intensively various ecological parameters so as to understand the ecological structure and functions of the study area. Random samples were taken in the field on both the sides of the road. Geographical position of the sampled plots was noted with the help of a Garmin eTrex 10 GPS handset (Fig. 18.1). No sample plots could be laid within GNP, as we did not have any permission to work within the protected area.

Fig. 18.1 Location of the sampling points (courtesy: Google Earth)
Z.B.: Zero Bandh near Tundu village close to Jaldhaka River (26° 46′ 18.11″ N and 88° 52′ 44.04″ E)
GNP Gate: GNP entry point (26° 47′ 41.80″ N and 88° 47′ 83.01″ E)
T.P.N.: West of the road, GNP touching point with the road in north (26° 47′ 40.84″ N and 88° 47′ 54.10″ E)
B.T.P.: West of the road, between the two GNP touching points with the road (26° 46′ 40.81″ N and 88° 47′ 48.15″ E)
T.P.S.: West of the road, GNP touching point with the road in south (26° 44′ 47.36″ N and 88° 46′ 45.74″ E)
N.R.B.: Neora River railway bridge (on the eastern side opposite to Saraswati forest village) (26° 44′ 37.70″ N and 88° 45′ 37.00″ E)
B.R.: Railway crossing on the Baradighi road (Lataguri-Neora More-Baradighi-Caltex More-Malbazar) which is proposed as an alternate route for making a traffic overpass (26° 46′ 13.86″ N and 88° 44′ 18.72″ E)
E.P.: GNP entry point (26° 47′ 41.80″ N and 88° 47′ 83.01″ E)
Green line extending from T.P.N. to T.P.S.: Area demarcated for tree felling

Besides random sampling, a study of all available species on both sides of the road in line transect was done to record composition of herbaceous vegetation, shrubs and trees. Plant specimens were identified using keys to the genera and species (Prain 1903). The inventory of species was prepared based on the data collected from both sides of the road within 30 m in both eastern and western side of the road passing in south to north direction. One-time data was collected in the month of May 2017 starting from 26° 43′ 15.40″ N and 88° 46′ 05.98″ E to 26° 44′ 47.36″ N and 88° 46′ 45.74″ E. Data for the inventory of plant species were also collected from eight points (Fig. 18.1) using quadrat method which were not included within the line transects. Those locations were within the migratory route of many wildlife species while travelling to Neora River for water.

Canopy cover was measured by direct estimation of canopy cover method during midday. Quadrat plots of 1 m × 1 m were placed randomly along a 100 m transect in the sampled plots where there were tree covers. Estimation of canopy cover was done by recording the percentage of total area to that of sunlit area in a graph paper. The limitation of this method is that estimates are very subjective.

A study on ethnomedicinal importance of plant species was also done by interviewing local villagers of Bichabhanga Banabasti (Forest Village) after taking their consent. Knowledge from ten local herbalists was utilized for calculating use values (Phillips and Gentry 1993) of medicinal species.

18.3.2 Biomass Estimation

Data obtained from the documents signed by the Beat Officer, Central Beat, Lataguri 551 (five hundred and fifty-one) indicated that trees were felled within in April 2018 and after vacating ‘stay order’ of the Hon’ble National Green Tribunal. Tree specimens were randomly chosen on the basis of species, girth class and height class for biomass estimation. Tree species felled were also recorded (Table 18.4, Fig. 18.2) which were 14 in number. Girth at breast height (GBH) and height of the trees were measured and recorded by the Beat Officer, Central Beat of Lataguri, under Jalpaiguri Forest Division of the FD, Govt. of West Bengal. The Beat Officer of FD used the standard ‘volume table’ for calculating the volume of the trees. This is in accordance with universally used general volume table equation devised by the Food and Agriculture Organization (FAO). General volume equations (GVEs), i.e. regression equations consisting of volume, diameter and height, specific for each species, were formulated utilizing randomly obtained tree data (Rawat et al. 2003). Volume of trees was measured by the best fit equation. The following regression equation (i) is used in this case.

$$V = a + BD^2H$$

Fig. 18.2 Indiscriminate felling of trees on both sides of the highway passing through GNP (courtesy: Dr. Tapan Kumar Mishra)

where V is the volume under bark (m^3), D is the diameter at breast height (1.37 m) over bark (from the data obtained from the Forest Beat Officer), H is the height of tree (m), a is the intercept and b is regression coefficient.

This biomass is only above ground biomass (AGB) timber biomass which is otherwise known as above ground 'merchantable' in the terms of International Timber Market.

Total biomass removed due to felling/total biomass of a tree = Above Ground 'merchantable'/timber biomass + Above ground non-merchantable biomass including components such as removable barks, tree tops, branches, twigs, foliage, sometimes stumps + below ground biomass (BGB).

The biomass was estimated using volume and specific gravity of *Schima wallichii* following Richter and Dallwitz (2000) as 61% of the tree specimens belonged to this species (as per the records of the FD). *Schima wallichii* is locally known as Chiloni/ Chillon/Makri sal. Here specific gravity of *S. wallichii* is considered to be 6.85, the mid-value of the range stated by the author. The reason behind taking mid-value is that it can represent all the trees felled irrespective of various girth classes and heights.

Therefore, merchantable AGB (in tons) of the trees felled = Volume (in m^3) x specific gravity of *S. wallichii.*

18.3.3 Secondary Information

Various publications by noted authors who worked on vegetation as well as wildlife diversity of GNP had been studied and referred to get the following information regarding GNP and other reserve forest areas adjacent to it. Publications linked with similar other habitats and their problems were also studied to address various issues connected with their conservation and management.

Identification and listing of species of conservation significance (rare, endangered, endemic and threatened (REET) species) in accordance with IUCN, WCMC, BSL ZSI, WPA 1972 and BirdLife International, secondary field database, published flora and endemic species in the study area were done. Wild Life (Protection) Act (1972) and its amendments were also referred to for lists of wildlife available in its Schedules. Prediction of present and future impacts on biodiversity as a whole and identification of conservation measures framed into conservation plan taking into consideration various legal measures, regulation and guidelines like the Biological Diversity Act (2002), Wild Life (Protection) Act (1972), Forest Conservation Act (1980), and rare and endangered plants from the Red List of plants (BSI ENVIS Resource Partner on Biodiversity). As GNP is a MPCA (Medicinal Plant Conservation Area), various species of medicinal plants are conserved in situ. Previous ethnobotanical studies by various authors were also referred to for understanding the structure of the ecosystem.

Discussion on various aspects of wildlife movement and other day-to-day management activities was done with ground-level staff of FD and people residing in Bichabhanga Banabasti to understand the intensity of disturbance. This forest village was located within the tree-felled area.

18.4 Results and Discussion

18.4.1 Flora and Canopy Cover in the Study Area

In the study area, where trees were felled, 86 plant species could be identified out of which 55 species were herbs and shrubs, 29 species were trees and 3 species were pteridophytes. A list of plant species identified during the study outside the GNP area, where felling has been undertaken, is attached in Table 18.1, Table 18.2 and Table 18.3. The forest area studied, apart from the road side, had a closed canopy cover of above 70% of considerable height with mostly tall trees and an entirely shaded forest floor covered with leaf litter. The studied locations consisted of trees like *Shorea robusta*, *Schima wallichii*, *Cassia fistula*, *Michelia champaca*, *Bombax ceiba*, *Phyllanthus emblica*, *Terminalia* spp., *Dillenia indica*, *Syzygium* spp., *Amoora wallichii*, *Sterculia villosa*, etc. The trees, generally found within the forests that were both economically and ecologically vital, consisted of *Shorea robusta* along with its normal associates like *Schima wallichii*, *Magnolia champaca* and

Table 18.1 List of tree species found within the study area

Sl. No.	Scientific name	Family
1.	*Aesculus indica* (Wall. ex Cambess.) Hook.	Sapindaceae
2.	*Amoora spectabilis* Miq.	Meliaceae
3.	*Baccaurea sapida* (Roxb.) Müll.Arg.	Phyllanthaceae
4.	*Bombax ceiba* L.	Bombacaceae
5.	*Casearia graveolens* Dalzell	Salicaceae
6.	*Cassia fistula* L.	Fabaceae
7.	*Dillenia indica* L.	Dilleniaceae
8.	*Duabanga sonneratioides* (Roxb. ex DC.) Walp.	Lythraceae
9.	*Garcinia elliptica* Wall.	Clusiaceae
10.	*Gynocardia odorata* R.Br.	Achariaceae
11.	*Ilex godajam* Colebr. ex Hook.f.	Aquifoliaceae
12.	*Lagerstroemia flos-reginae* Retz.	Lythraceae
13.	*Lannea coromandelica* (Houtt.) Merr.	Anacardiaceae
14.	*Litsea chinensis* Lam.	Lauraceae
15.	*Litsea hookeri* (Meisn.) D.G.Long	Lauraceae
16.	*Magnolia pterocarpa* Roxb.	Magnoliaceae
17.	*Mallotus philippensis* (Lam.) Müll.Arg.	Euphorbiaceae
18.	*Michelia champaca* L.	Magnoliaceae
19.	*Phyllanthus emblica* L.	Euphorbiaceae
20.	*Premna bengalensis* C.B.Clarke	Lamiaceae
21.	*Saurauia roxburghii* Wall.	Ericales
22.	*Schima wallichii* (DC.) Korth.	Theaceae
23.	*Shorea robusta* Gaertn.	Dipterocarpaceae
24.	*Syzygium formosum* (Wall.) Masam.	Myrtaceae
25.	*Sloanea sterculiacea* (Benth.) Rehder & E.H. Wilson	Elaeocarpaceae
26.	*Sterculia villosa* Roxb.	Sterculiacea
27.	*Syzygium jambolanum* DC.	Myrtaceae
28.	*Terminalia bellirica* (Gaertn.) Roxb.	Terminaliaceae
28.	*Terminalia chebula* Retz.	Terminaliaceae
29.	*Tetrameles nudiflora* R.Br.	Tetramelaceae
30.	*Wrightia arborea* (Dennst.) D.J. Mabberley	Apocynaceae

Terminalia bellirica. Significant understory species seen in the roadside buffer zone of GNP included *Andrographis paniculata*, *Dioscorea* spp., *Bauhinia purpurea*, *Rauvolfia serpentina*, *Smilax prolifera*, *Holarrhena pubescens*, etc. GNP area was surrounded by patches of plantations of *Acacia catechu*, *Lagerstroemia parviflora*, *Bambusa* spp., *Phyllanthus emblica*, *Dillenia indica*, etc.

Out of the total number of plant species found as result of field survey, four species were threatened that need in situ conservation efforts. The conservation status of each plant species was mentioned following Das et al. (2015). The local names, families and habits of the threatened species were tabulated (Table 18.5).

Table 18.2 List of shrub and herb species found within the study area

Sl. No.	Scientific name	Family
1.	*Achyrospermum wallichianum* (Benth.) Benth. Ex Hook.f.	Lamiaceae
2.	*Ageratum conyzoides* L.	Asteraceae
3.	*Amaranthus* sp.	Amaranthaceae
4.	*Amaranthus viridis* L.	Amaranthaceae
5.	*Andrographis paniculata* (Burm. f.) Wall. ex Nees	Acanthaceae
6.	*Asparagus racemosus* Willd.	Liliaceae
7.	*Axonopus compressus* (Sw.) P. Beauv.	Poaceae
8.	*Bauhinia purpurea* L.	Fabaceae
9.	*Cardiospermum halicacabum* Linn.	Sapindaceae
10.	*Cassia tora* L.	Fabaceae
11.	*Centella asiatica* (L.) Urb.	Apiaceae
12.	*Cheilocostus speciosus* (J. Koenig) C. Specht	Zingiberaceae
13.	*Clerodendrum indicum* (L.) Kuntze	Verbenaceae
14.	*Crinum* sp.	Liliaceae
15.	*Crotalaria pallida* Aiton	Fabaceae
16.	*Croton oblongifolius* Roxb.	Euphorbiaceae
17.	*Cynodon dactylon* (L.) Pers.	Poaceae
18.	*Cynoglossum amabile* Stapf & J.R.Drumm.	Boraginaceae
19.	*Cyperus* sp.	Cyperaceae
20.	*Dactyloctenium indicum* (L.) Willd.	Poaceae
21.	*Digitaria sanguinalis* (L.) Scop.	Poaceae
22.	*Dioscorea alata* Linn.	Dioscoreaceae
23.	*Dioscorea bulbifera* Linn.	Dioscoreaceae
24.	*Dioscorea pentaphylla* Linn.	Dioscoreaceae
25.	*Eclipta prostrata* (L.) L.	Asteraceae
26.	*Glycosmis arborea* (Roxb.) DC.	Rutaceae
27.	*Grewia asiatica* L.	Euphorbiaceae
28.	*Heliotropium indicum* L.	Boraginaceae
29.	*Helminthostachys zeylanica* (L.) Hook.	Helminthostachyaceae
30.	*Holarrhena pubescens* (Buch.-Ham.) Wall. ex G.Don.	Apocynaceae
31.	*Holmskioldia sanguinea* Retz.	Lamiaceae
32.	*Lasia spinosa* Linn.	Araceae
33.	*Leucas indica* (L.) R.Br. Ex Vatke	Lamiaceae
34.	*Luffa aegyptiaca* Mill.	Cucurbitaceae
35.	*Mecardonia procumbens* (Mill.)	Scrophulariaceae
36.	*Melastoma malabathicum* L.	Melastomataceae
37.	*Mucuna pruriens* (L.) DC.	Fabaceae
38.	*Oplismenus burmannii* (Retz.) P.Beauv.	Poaceae
39.	*Osbeckia chinensis* L.	Melastomataceae
40.	*Oxalis corniculata* Linn.	Oxalidaceae
41.	*Paspalidium flavidum* (Retz.) A.Camus	Poaceae
42.	*Phyllanthus simplex* Retz.	Euphorbiaceae

(continued)

Table 18.2 (continued)

Sl. No.	Scientific name	Family
43.	*Phyllanthus virgatus* G.Forst.	Euphorbiaceae
44.	*Physalis minima* Linn.	Solanaceae
45.	*Plumbago zeylanica* Linn.	Plumbaginaceae
46.	*Polygonum* sp.	Polygonaceae
47.	*Rauvolfia serpentina* (L.) Benth. Ex Kurz	Apocynaceae
48.	*Ruellia prostrata* Poir.	Acanthaceae
49.	*Scoparia dulcis* Linn.	Scrophulariaceae
50.	*Sida acuta* Burm.f.	Malvaceae
51.	*Smilax prolifera* Roxb.	Smilacaceae
52.	*Solanum nigrum* L.	Solanaceae
53.	*Solanum americanum* Mill.	Solanaceae
54.	*Tabernaemontana divaricata* (L.) R.Br. ex Roem. & Schult.	Apocynaceae
55.	*Wrightia tinctoria* R. Br.	Apocynaceae

Table 18.3 List of pteridophyte species found within the study area

Sl. No.	Scientific name	Family
1.	*Helminthostachys zeylanica* (L.) Hook.	Helminthostachyaceae
2.	*Diplazium esculentum* (Retz.) Sw.	Athyriaceae
3.	*Ophioglossum reticulatum* L.	Ophioglossaceae

Table 18.4 List of tree species felled

Sl. No.	Scientific name	Local name
1.	*Amoora spectabilis* Miq.	Lali
2.	*Bombax ceiba* L.	Simul
3.	*Chukrasia tabularis* A. Juss.	Chikrassi
4.	*Cassia fistula* L.	Bandar lathi
5.	*Dalbergia sissoo* Roxb. Ex DC.	Sisu
6.	*Dillenia indica* L.	Chalta
7.	*Ficus benghalensis* L.	Bot
8.	*Lagerstroemia parviflora* Roxb.	Jarul
9.	*Lannea coromandelica* (Houtt.) Merr.	Jiola
10.	*Schima wallichii* (DC.) Korth.	Chiloni
11.	*Shorea robusta* Gaertn.	Sal
12.	*Tectona grandis* L.f.	Segun
13.	*Terminalia bellirica* (Gaertn.) Roxb.	Bahera
14.	*Terminalia chebula* Retz.	Haritaki

Table 18.5 List of threatened floral species in the study sites

Sl. No.	Scientific name	Local name	Family	Conservation status
1.	*Gynocardia odorata* R.Br.	Chalmogra	Flacourtiaceae	EN
2.	*Helminthostachys zeylanica* (L.) Hook.	Ekbir	Helminthostachyaceae	EN
3.	*Ophioglossum reticulatum* L.	Ektir	Ophioglossaceae	EN
4.	*Rauvolfia serpentina* Benth. Ex Kurz	Sarpagandha	Apocynaceae	EN

EN = Endangered

18.4.2 Ethnobotanical Study of Identified Medicinal Flora

Being within the Medicinal Plant Conservation Area (MPCA), GNP has good number medicinal plant species. Earlier studies documented 127 species (36 trees, 34 shrubs and 57 herbs) of medicinal plants locally utilized by the people (Saha et al. 2013).

Even outside GNP, i.e. in the present study area, there were 7 species of trees and 17 species of herbs and shrubs that were regularly used by local people. Majority of the uses were focussed on managing and curing a wide range of human ailments. The plant parts used, local names and use values of such medicinal plant species were tabulated (Table 18.6). The tree species (*Cassia fistula*, *Phyllanthus emblica*, *Terminalia bellirica*, *Terminalia chebula*) mostly had higher use values followed by a climber (*Dioscorea bulbifera*) and a herb (*Andrographis paniculata*).

18.4.3 Impacts of Large Scale Tree Felling

Large-scale tree felling in the buffer zone of GNP is going to have a cascading effect on the ecosystems as well as species diversity of the national park and on its buffer zone. It is apprehended that there will be a huge adverse impact on wildlife habitat and their corridors, on the species structure of floral component and the functional interrelationship between its physical and biological components of the GNP. Therefore, a review was needed to be undertaken in larger interest of ecology of the GNP and looming large threat of climate change.

18.4.4 Enrichment of Atmospheric Carbon

Release of sequestered carbon in the form of CO_2 to the atmosphere due to felling of trees has been huge. In the following steps, contribution of CO_2 to the total atmospheric GHG is calculated.

Table 18.6 Parts used and use values of medicinal plant species in the study sites

Sl. No.	Scientific name	Local name	Parts used	Use values
1	*Cassia fistula* Linn.	Bandarlathi	Leaves, bark, root, seeds	10.3
2	*Dillenia indica* Linn.	Chalta	Barks, leaves, fruits	3.6
3	*Phyllanthus emblica* Linn.	Amlaki	Fruits, leaves	7.5
4	*Shorea robusta* Gaertn.	Sal	Resin and leaves	3.6
5	*Syzygium jambolanum* DC.	Jam	Bark, leaves and fruits	4.2
6	*Terminalia bellirica* (Gaertn.) Roxb.	Kathbadam	Fruits and bark	7.5
7	*Terminalia chebula* Retz.	Haritaki	Fruits	7.5
8	*Ageratum conyzoides* Linn.	Bhusbhuse	Leaves, flowers, roots, whole plant	2.5
9	*Andrographis paniculata* (Burm.f.) Wall. ex Nees	Kalmegh	Whole plant	7.6
10	*Asparagus racemosus* Willd.	Satamuli	Roots	5.9
11	*Dioscorea alata* Linn.	Chuprialu	Tubers	5.8
12	*Dioscorea bulbifera* Linn.	Chuprialu	Tubers	8.5
13	*Dioscorea pentaphylla* Linn.	Pachpata alu	Tubers, shoot	2.4
14	*Holarrhena pubescens* (Buch.-Ham.) Wall. ex G.Don.	Kurchi	Bark, stem latex	3
15	*Lasia spinosa* Linn.	Kantakacu	Leaves, inflorescence	2.3
16	*Leucas indica* (L.) R.Br. Ex Vatke	Murti	Leaves, young twig	1.6
17	*Oxalis corniculata* Linn.	Ambalisak	Whole plant	3.9
18	*Plumbago zeylanica* Linn.	Chita	Roots	5.3
19	*Phyllanthus virgatus* G.Forst.	Bidhira	Roots	1
20	*Physalis minima* Linn.	Bantepari	Whole plant	3
21	*Rauvolfia serpentina* Benth. Ex Kurz	Sarpagandha	Roots	4.5
22	*Scoparia dulcis* Linn.	Misti pata	Whole plant	5.2
23	*Sida acuta* Burm.f.	Jharugachh	Leaves and roots	2.9
24	*Solanum americanum* Mill.	Kalebegun	Tender shoots	6.6

(a) Estimation of above ground biomass or AGB (merchantable).

$$\text{AGB} = \text{volume in m}^2 \times \text{Specific gravity of } S.wallichhii$$

AGB = Merchantable AGB (in tons) of the trees felled

i.e. 322.721 $m^3 \times 6.85$ tons = 2210.639 tons. This is only the merchantable AGB of the trees felled as stated above.

(b) AGB (non-merchantable): This biomass could not be calculated in the field directly. There is also no such acceptable formula available in India to get an idea of the biomass of the removable barks, tree top, leaves, twigs, non-commercial tree trunks and branches. Here a ‘calculator’ has been used for the category ‘Mixedwood Plains-Unidentified Hardwood-Treed Broadleaf-

Dense Forest' only to understand the probable ratio of this category to merchantable timber biomass (Canada's National Forest Inventory 2016).

The ratio between AGB (merchantable) to AGB (non-merchantable) is 1.9: 0.9. Using this ratio, the AGB (non-merchantable) is calculated to be 1047.145 tons (0.9/1.9 × 2210.639).

(c) Calculation of below ground biomass or BGB.

In the tropical moist deciduous forests, the root system weighs 24% as per IPCC Guidelines for National Greenhouse Gas Inventories, Volume 4 (Carle and Murthy 2006), as much as the AGB. Therefore, the root biomass is 2210.639 tons × 0.24 = 530.554 tons.

(d) Calculation of the total biomass.

$$\text{The total biomass} = \text{AGB (merchantable)} + \text{AGB (non} - \text{merchantable)} + \text{BGB}$$

i.e. 2210.639 + 1047.145 + 530.554 = 3788.338 tons is the biomass of the 551 trees felled.

(e) Calculation of immediately decomposable/fuel biomass.

ABG (non-merchantable) components and BGB (root system) are going to be decomposed/burnt as fuelwood within few days from the day of felling. This immediately decomposable/fuelwood biomass is 1047.145 tons+530.554 tons = 1577.699 tons, i.e. this is about 42% of the total biomass which is a significant amount.

(f) Estimation of carbon stored in the felled trees.

Estimation of carbon stored or in other words supposed carbon loss due to wood removal is done following 2006 IPCC Guidelines for National Greenhouse Gas Inventories (Volume 4: Agriculture, Forestry and Other Land Use) in tropical and subtropical forests. The conversion factor for converting biomass to carbon is 0.49.

Therefore, the amount carbon emitted/going to be emitted due to this large-scale felling is as follows:

$$3788.338 \text{ tons} \times 0.49 = 1856.286 \text{ tons of carbon}$$

(g) Calculation of carbon dioxide sequestered in the felled trees.

Determination of the weight of carbon dioxide sequestered in the felled trees during the period of their existence is calculated by multiplying the weight of carbon in the tree by 3.67 (multiplying by the ratio of the molecular weight of carbon dioxide to that carbon, i.e. 44/12).

$$1856.286 \text{ tons carbon} \times 3.67 = 6812.568 \text{ tons of } CO_2.$$

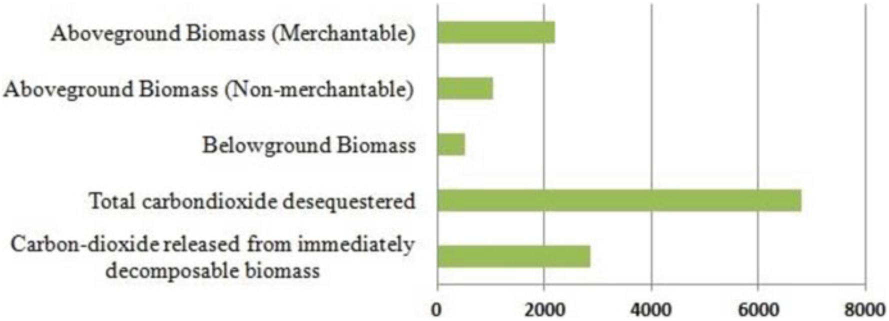

Fig. 18.3 Biomass removal vis-a-vis carbondioxide desequestered due to large scal tree felling (in tons)

The calculations depict that slightly less than 7000 tons of CO_2 have been unleashed to the atmosphere in spite of the fact that there was an alternate road where widening could be done with minimal felling of trees. This CO_2 is going to add to the pool of GHG that is already present in the atmosphere.

For the sake of argument if it is accepted that the timber part (merchantable biomass) is not going to be decomposed immediately, then the immediately decomposable part is going to release 2861.278 tons of CO_2. A bar diagram representing comparative account of extracted biomass and CO_2 released is displayed in Fig. 18.3.

18.4.5 Impact on Plant Species Diversity

Land clearing for widening of roads often assists in the establishment and spread of invasive species (Lázaro-Lobo and Ervin 2019). Such invasions are facilitated by the roads as the exotic plants confront less rivalry from already existing plant species in a newly clear-felled area. We observed that among the flowering plants, *Eupatorium odoratum*, *Lantana camara*, *Mikania indica* and *Ageratum conyzoides* exhibited aggressive invasions in this forest fringe area. Frequent physical disturbances in the form of highway construction and their orderly maintenance, vehicular traffic and right of way may help the invasive species to become advantageous (Pickering and Hill 2007).

Generally, impact of rainfall is more intense on the edge of the road than in the interior forest, which can cause more damage to the saplings near the road. Dispersal of seeds and other propagules of affected vegetation on road sides that are heavily disturbed in the wide roads eventually become isolated and lose viability.

18.4.6 Habitat Fragmentation and Increase in Road Kill

It is evident that a road dissects contiguous habitat patches resulting in higher edge-to-interior ratios. This causes increased disturbance to long-ranging animals like elephants, gaurs, rhinos, etc. Fragmentation of habitat has caused substantial decline in amphibian population worldwide during the last century (Stuart et al. 2004). A noteworthy 56.17% decrease in the grassland cover and 23.83% increase in the woodland cover were observed during a time span of 20 years (Mukherjee et al. 2019). The state forest department also reported 50.82 ha as total area under encroachment as on 31.03.2020.

The present road passing through Gorumara has envisaged number of road kills of wild fauna both in the past and in the present. On an average, 239 wild animals were getting killed every year on this highway (Table 18.7). Deaths of Schedule I animals like leopard cats, fishing cats, leopards, gaurs, ferret badgers, civet cats and a large number of reptiles, amphibians and birds are frequent on this stretch of road (SPOAR 2020). It is evident that the proposed overbridge on the railway track will enhance road traffic to a great extent. As per our estimation, the present traffic load was hardly 300 vehicles per day on NH31. Increased traffic flow will also have many adverse consequences.

It is specifically mentioned by the field-level forest staff and so also by the villagers that during late winter and summer water, scarcity compels long-ranging animals to move westwards to Neora River in search of water. The existing road is a hurdle, and therefore many road kills and confrontations have been recorded. One such artificial water source made at Garapi within GNP is now facing problem of existence due to lack of management.

Widening of road that crosses a wildlife habitat will enhance probability of road kill of some animal species as they will spend more time to cross a wider road. In fact, death due to vehicular collisions on highways is the leading source of mortality for many wildlife populations worldwide (Hill 2015). A number of studies had quantified and documented road kills of diversified vertebrates and invertebrates including amphibians, birds, mammals like deer and other ungulates, reptiles and butterflies (Drews 1995; Fahrig et al. 1995; Groot and Hazebroek 1996). Reptiles like snakes and even turtles occasionally sunbathe on the warm road asphalt for regulation of body temperatures particularly during colder months. Turtles often identify cars as threats and are more susceptible to vehicular collision by drawing into their shells as a measure of protection that keeps them longer on the roads (Gooley 2010). Snakes may stay in an immobilized state for some time when approached by a vehicle (Andrews et al. 2005). Locomotion and movement during

Table 18.7 Road kill numbers at Gorumara and Dhupjhora (source: Society for Protecting Ophiofauna and Animal Rights 2020)

Year	No. of survey days	Total no. of roadkill
2014–2015	31	247
2015–2016	43	389
2016–2017	45	403
2017–2020	39	394

specific life phases can also lead to a pinnacle in road mortality. Male individuals of some snake species, in their look for potential females, can amplify their home ranges up to six times during their breeding and nesting season (DeGregorio et al. 2010).

Furthermore, arboreal animal populations like that of rhesus monkeys are subjected to fragmentation into a number of smaller sub-populations that in due course suffer from inbreeding depression and genetic homogeneity and driven to local population extinction (Kumar et al. 1995). Apart from the presence of prohibited human practices like poaching, capturing or collecting scheduled wild animals and plants in the park, developmental activities such as building of railways and national highways as well as electrification are also largely accountable for biodiversity loss (Ray et al. 2018).

18.4.7 Barrier Effect on Wildlife

It is generally conceived that road widening will have no additional effect on wildlife, but Wildlife Institute of India (WII 2016) is of the opinion that road extensions result in both increase of traffic volume and velocity and hence act as impediment to animal movements across the highways. By using a model of 'barrier effect' in both two and four lane sections and some species-specific features like body size, behaviour, mean size of group, average time taken to cross the road, road breadth, traffic volume and vehicle diversity, WII has inferred that all these factors determine the success of traversing by the wild animals. It also depicts that a wide road pose as a 'barrier' to their movement. Though there will be a decrease in animal mortality, it will also prevent them from utilizing their whole habitat leading to a reduction in genetic fitness.

Habitat loss due to fragmentation, mortality owing to vehicular collisions, pollution and metal poisoning are the direct effects of road building on neighbouring bird communities. Indirect effects including noise, headlight glare, obstacles to movement and road boundaries also exerted a larger influence on bird populations. Decline in avian population densities and richness could be the outcome of the collaborative influence of direct and indirect impacts (Kociolek et al. 2011). Rising habitat fragmentation and climate change-driven forecasted shifts in species distribution are expected to intensify the all-inclusive effects of road making and road expansion on avian communities.

18.4.8 Increase in Human-Wildlife Conflicts (HWH)

According to annual state wildlife report (2018–2019), human-leopard, human-elephant and human-gaur conflict zones were demarcated in and around GNP. Owing to increasing population pressures of both human and other wild animals

Table 18.8 Ex gratia relief for animal depredation paid by the state forest department in GNP and forest fringe areas, West Bengal (source: data obtained from Aranya Bhavan, Jalpaiguri)

Year	No. of people killed	No. of people injured	No. of livestock animals killed/injured	No. of huts damaged	Area of agricultural land destroyed in ha	Total compensation paid
2019–2020	20	108	4	8	29.79	64,83,732
2009–2010	–––	–––	–––	62 (partially damaged)	9.57	1,97,524

as well as habitat fragmentation as a result of road expansion and illegal encroachments, human-wildlife conflicts and hence the compensations paid had increased manifold in the last 10 years (Table 18.8). 117 human deaths and injuries were observed during 2009–2013 at Gorumara and Jalpaiguri Forest Divisions as an outcome of wild animal-human conflicts (Roy 2018). Highest number of cases was reported due to elephants followed by leopards and gaur. Types of damages due to wildlife also include killing of livestock and destruction of houses and croplands. It is therefore apprehended that tree felling, overbridge construction and consequent widening of roads will further aggravate this problem.

18.4.9 Unplanned Plantation Programmes in GNP

Another threat to the loss of biodiversity is unplanned plantation within the park area. In many areas of GNP, large-scale conversion of natural forests into Teak and Jarul monoculture plantations during Sixth and Seventh Working Plan periods prior to the establishment of the National Park and Wildlife Sanctuary was unfavourable for sustaining diverse forms of lives. Teak and Jarul plantations occupy 34% of the total plantations in the protected areas in this region (Debnath et al. 2017).

18.4.10 Other Predicted Impacts

Increased traffic volume adjacent to GNP will inject more pollutants like oxides of carbon, nitrogen, sulphur, heavy metals and particulates in the air generated due to burning of fossil fuels. Soils of roadside buffer areas can also have increased metal concentrations (Neher et al. 2013). These toxic air pollutants will have a negative impact on the forest ecosystem as a whole and may surpass tolerable limit. Forest clearance would certainly initiate concretization though construction of more tourist and real estate mushrooming across the length of this highway. A beautiful forest, which is already seeing ingress of lakhs of visitors and affecting wildlife, would be turning into a human habitat and endangering wildlife badly in days to come.

18.5 Conclusion and Recommendations

In the area of felling within the buffer zone of GNP, we identified 86 floral species (29 trees; 55 herbs, shrubs and woody climbers; 3 pteridophytes) including 4 endangered species. 24 species from the buffer zone were of ethnomedicinal importance and were exploited as cure for a lot of human diseases. Carbon emission was about 7000 tons from the felled buffer area. Collected data also showed an annual average of 239 wildlife deaths on the national highway passing through the park's periphery. We also found out that ex gratia relief for animal depredation paid by the forest department (FD) increased almost 32.8 times in the last 10 years at GNP and its fringes revealing a considerable rise in intensity of human-wildlife conflicts.

Strategy for conservation of wildlife does not only mean protection of rare and endangered species rather taking up a holistic management plan of all the species in the habitat. Nowadays landscape conservation is more relevant than conservation at the species level. National parks, in our country, are conservation areas of highest order because they have valuable wildlife habitats within it and corridors around it. These wildlife corridors are also being severely impacted due to developmental projects inside forestland. There is a lack of integration of wildlife safety in the planning of most anthropogenic projects resulting in irreversible damage to the ecosystem. Thus, in a national park, linear development projects such as road construction and expansion are consistently in conflict with the aims of conservation. Manoj et al. (2013) while reviewing the forest wildlife scenario of northern West Bengal have suggested that for every project, environmental impact assessment must be carried out by an external independent agency.

It is suggested that vehicles which use the aforesaid stretch of National Highway No. 31 can avail of an already existing alternate route passing through – Lataguri-Neora More-Baradighi-Caltex More-Malbazar. This route can suitably bear heavy traffic movement between Malbazar and Chalsa. This road is under the Pradhan Mantri Gram Sadak Yojana (PMGSY) and has bitumen surface. This road will have least impact on wildlife in particular and biodiversity at large because it does not have dense forests in either side of it. In this case, the flyover can be built at the railway crossing having GPS bearing (N) 26° 46′ 13.86″ and (E) 88° 44′ 18.72″ at an altitude of 102 m. A map (Fig. 18.4) with a drawn alternate route shows that proposed alternate route does not have a good vegetation cover on its either side for a considerable stretch and never touches GNP at any point. This route was used successfully in several occasions and on the days while tree felling and protests took place on NH 31. Therefore, it was suggested that an already existing alternate route west to the Neora River, hardly 5 km more than the present one, could have been widened and developed for enhanced traffic. This would have minimized disturbance being caused to the GNP and road kills.

Following the guidelines laid down in National Wildlife Action Plan (2002–2016), it is also suggested that the present road (NH No. 31) passing adjacent to the GNP be closed every night, i.e. dusk to dawn, to enable the wildlife to use their corridors freely across the road. During this period, the alternate road stated above

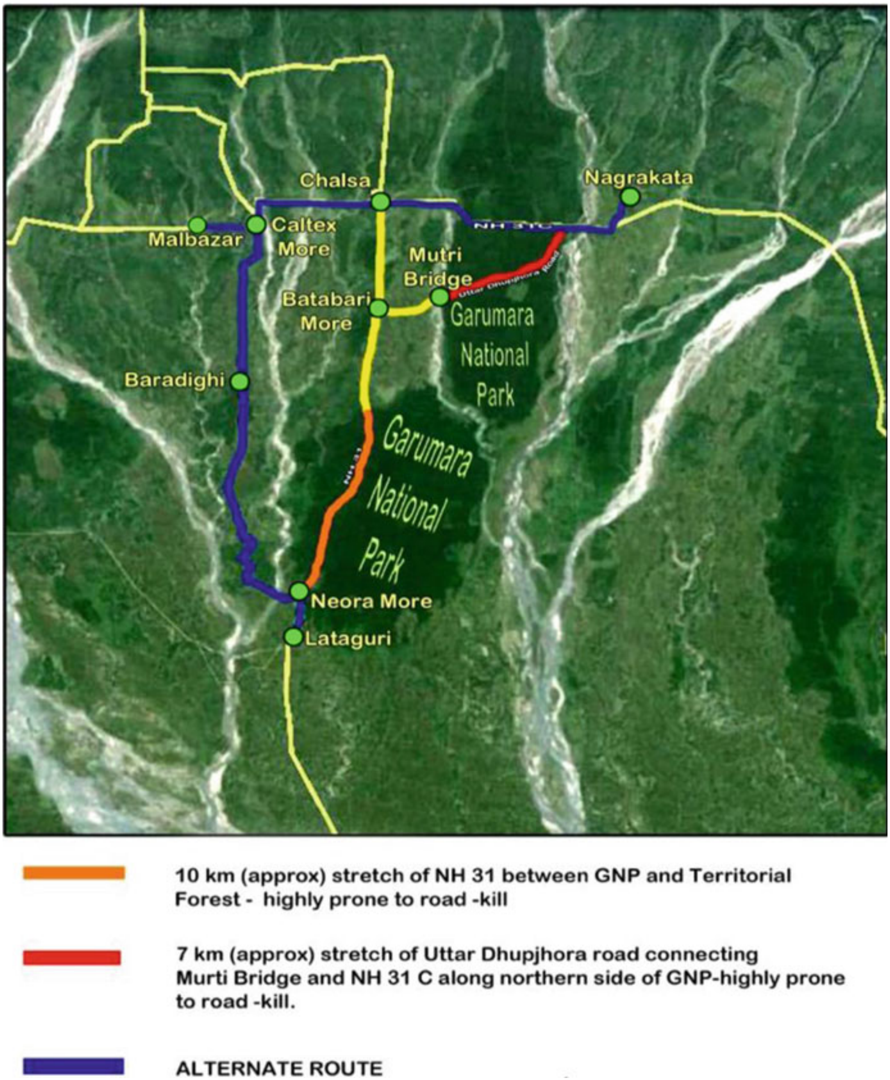

Fig. 18.4 Map of GNP with proposed alternate route (courtesy: Google Earth)

may be used causing very little damage to GNP. Prospective measures for remediation of the negative effects of roads on wild bird populations include noise minimizing strategies and alterations in roadway lighting, plant cover and stream of traffic (Kociolek et al. 2011). Native plant species that act as insulators and are well adapted to low resource availability should be cultivated in the forest fringe areas. Contamination of the environment with chemicals can be prevented by minimizing the transport system's physical impact and maintaining indigenous plant belts (Neher et al. 2013).

Participatory in situ conservation strategies are to be properly implemented in order to save species of REET category as stated above as well as wildlife species of Schedule I and Schedule II. This needs knowing the places of availability of the species, their niche strategy and their reproduction/propagation behaviour and making people aware so that every stakeholder can take proper care.

Similarly, conservation of medicinal plants available in the study area deserves proper attention of the conservators. Canopy exposure due to large-scale felling of trees will harm the ground vegetation to a large extent. Most of the medicinal plant species belong to the category of herbs and shrubs. Therefore, these species need rehabilitation and participatory conservation in a new area. A wildlife conservation and management plan (WCMP) has to be prepared with experts in the field. This may include structural options and non-structural options like suitably made canopy bridges for rhesus monkey population and other arboreal animals, holistic habitat management plan, corridor plantings, local traffic management, etc. It is evident that movement of wildlife does not confine to the boundaries of a national park. Whether a long-ranging or short-ranging animal, they can roam within the park and always use its periphery, also known as its buffer zone as their niche. This proposed wildlife conservation and management plan should address all these issues.

Ample arrangement of water sources by making new water holes and management of existing water holes like that of the existing one at Garapi has to be done. There is also lack of sufficient salt licks for wildlife within the park. Artificial salt licks are to be suitably placed as per suggestions of WCMP to provide required nutrients supplementing their diet.

To conclude, it can be emphatically said that there is enough space available in making alternate conservation strategies to protect the national park. There is no doubt of the fact that a blunder has been committed to the GNP by felling such a large number of trees which can hardly be undone. Making an overbridge or widening of a road within a wildlife habitat cannot be called as a ‘development project’ unless it addresses the issues concerned with not only wildlife management but also the whole landscape management in and around Lataguri.

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Chapter 19
Assessing Potential Habitat Suitability for *Panthera tigris* Using Multiple Grain Size and Different Ensemble Methods in Maximum Entropy Modeling

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Abstract Habitat suitability is a foremost task in conserving wildlife and ecosystem. Rapid decline in wildlife and threat to their habitat due to unprecedented anthropocentric development and fragmentation of animal's habitat has increased likelihood of human-wildlife conflict. Rajaji Tiger Reserve (RTR), Uttarakhand, India, has the great potential to sustain the young migratory tigers. Present study aims to find out the suitability of *Panthera tigris* (tiger) at Chilla, Gohri, and Motichur ranges of RTR using presence-only species distribution modeling at multiple grain size. An ensemble model was developed with high precision. The influence of climatic variables for prediction of suitability of habitat for *Panthera tigris* was evaluated at 900 m grain size using the three approaches such as Maxent, Ecological Niche Factor Analysis, and Bioclim. Results show that all the three models performed well with accuracy of more than 0.7 ROC value. Factors such as distance from settlement, distance from waterbody, distance from railway track, mean NDVI, and elevation were the primary contributes for all the models. Bioclimatic variables did not contributed significantly to the habitat suitability of the

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species in the RTR. The results signify that overreliance on the climatic variables and constraining model at coarse resolution is not required. Ensemble model was prepared using Maxent and Ecological Niche Factor Analysis. Only Maxent highlights the effect of different grain size, i.e., 30 m grain size was having better accuracy in comparison to 900 m grain size, whereas all other models were having more or less the same accuracy at different grain size. Ensemble model showed that out of the 335 km^2 area, approximately 105 km^2 was suitable at 30 m grain size species distribution model (SDM), whereas 96 km^2 area was suitable at 900 m grain size model. The analysis resulted that RTR has the potential to sustain *Panthera tigris* population. Regulatory mechanism along with better implementation of rules and regulation is required to be implemented by the government and concerned department along with better awareness among the local residents for sustaining the wildlife and their habitat.

Keywords ENFA · Maxent · Niche modeling · SDM · Wildlife

19.1 Introduction

Forest and wildlife are important for maintaining ecological balance and healthy environment. However, rapid decline in wildlife and threat to their habitat due to unprecedented anthropocentric development is detrimental for overall functioning of the ecosystem (WWF 2020). The fragmentation of animal's habitat has increased substantially the chances of human-wildlife conflict (Acharya et al. 2017). Tiger (*Panthera tigris*) is a keystone species and is a top predator and prefers large habitat range (Kanagaraj et al. 2011). Loss in habitat due to conversion of forested landscape to human inhabitance forced tiger to sustain in the small, isolated, and shrank forested area leading to decline in their population (Smith et al. 1998). The species is declared as endangered by IUCN Red List. Moreover, the population of tiger has declined almost by 50% over three generations (http://www.iucnredlist.org/details/15955/0). The estimated population of tigers in India in 2014 was 2226 (with a range of 1945–2491). In Uttarakhand, a federal state of India, the tiger population has increased from 178 (with a range of 161–195) in 2006 to 227 (with a range of 199–256) in 2010 (Jhala et al. 2015). Times of India, a daily newspaper, has reported that Jim Corbett Tiger Reserve has 208 adult tigers, against 163 in 2015–2016, and 6 cubs, whereas Rajaji Tiger Reserve has 34 tigers, against 16 in 2015–2016, along with 5 cubs. Rajaji National Park (RNP), which attained the status of tiger reserve in 2015, holds the great potential to sustain many migratory young tigers specially in Chilla-Motichur corridor of RNP (1800 km^2) (Johnsingh 2006).

The population of tigers in the forests of the Uttarakhand has increased during the past decades; however, threats to curbing tiger population have been increased. The major factors responsible for restricting the tiger population in the state are poaching of tiger and its prey, habitat fragmentation and degradation, developmental activities, and conflict with humans in the region (Johnsingh 2006). Despite increase in population of tigers, shrinkage of tiger habitat is a matter of concern, e.g., habitat area for tiger in India has reduced from 93,600 km^2 in 2006 to 72,800 km^2 in 2010 (Kanagaraj et al. 2011). The disturbance in the ecological setting specially tiger (*Panthera Tigris*) population is detrimental as tigers are at the top level of food chain and directly or indirectly impacts the primary consumer (Imam and Tesfamichael 2013). Therefore, for conservation and protection of the tiger population, suitable policies may be framed by appropriately judging the potential factors responsible for unfavorable conditions for their population. Scientific method for judging the potential factors is evaluation of habitat suitability (Sharma et al. 2018).

Traditional or primitive methods for identifying the suitability of wildlife's habitat are equally important and, however, are costly as the required datasets are difficult to obtain (Imam and Tesfamichael 2013). Species distribution modeling (SDM) is a cost-effective technique for site suitability modeling and widely used as an important predictive technique for ecology, biogeography, and conservation biology (Guisan and Thuiller 2005). SDM has also the capability to predict high-quality habitat for number of species (Karwariya et al. 2017). SDM which is classified as empirical-based model primarily relies on statistical data evaluation by generalized linear model (GLM), generalized additive model (GAM), and Ecological Niche Factor Analysis (ENFA), and expert model primarily relies on the experts' opinions and perception (Dash et al. 2015). SDM is based on two sorts of data, i.e., presence-only data and presence/absence data. Approaches such as Maxent, ENFA, Bioclim, and Domain are examples of SDM based on presence-only data, whereas GLM, GAM, GARP, CART, random forest, and artificial neural network are examples of presence/absence data (Brotons et al. 2004). These models are capable for the prediction of presence and absence of geographical location and habitat suitability which might be potential areas for the wildlife species and therefore serve as a valuable technique for prediction of habitat suitability for the species to be introduced (Brotons et al. 2004). Usage of data such as categorical and continuous data in building SDM is of major concern. For example, Maxent uses both categorical and continuous data and mostly has the best prediction accuracy in comparison to other presence-only "SDM," whereas ENFA has the limitation that it can't take categorical data directly and requires conversion of categorical data into quantitative data by various methods available in the biomapper software (Hirzel et al. 2002). Besides, the modeling has also provided an important information about the conservation of endangered or vulnerable species or provides a risk zone map due to the potential spread of invasive species (Jiménez-Valverde et al. 2011).

"Species distribution models are empirical models relating field observations to environmental predictor variables, based on statistically or theoretically derived response surfaces" (Guisan and Zimmermann 2000a, b). Generally, SDM algorithm falls under three categories, namely, (i) expert-based (non-statistical, non-empirical) spatial modeling of species distribution, (ii) non-spatial statistical quantification of species-environment relationship based on empirical data, and (iii) spatially explicit statistical and empirical modeling of species distribution (Guisan and Thuiller 2005). Various SDM algorithms are used in the site suitability or habitat suitability of mammals, invasive species, or plant species (Farashi and Erfani 2018). Generalized linear models (GLM) and generalized additive model (GAM) are classic regression models and have substantial applications in SDM due to their strong statistical base with effective modeling of the realistic ecological relationship (Elith et al. 2006). Genetic algorithm for rule set production (GARP) is a machine learning algorithm which uses presence-only data for modeling suitable habitat and is robust for handling smaller samples of presence-only data (Peterson et al. 2007). However, Maxent algorithm overperformed this technique in terms of prediction accuracy (Li and Wang 2013). Bioclim was the first SDM model and most widely used in the SDM package, developed to predict the effect of climatic variables on species habitat's suitability (Booth et al. 2014). Ecological Niche Factor Analysis (ENFA) is a multivariate approach for presence-only data, used to study the geographic extent of species distribution and based on the factor analysis (Hirzel et al. 2002). Classification and regression tree (CART) is machine learning algorithm which uses recursive partitioning to decompose the data into homogeneous smaller subsets at its maximum possible extent (Breiman et al. 1984). CART can handle more complex interactions between predictors which might be difficult or impossible to interpret using traditional multivariate approach. Random forest, a modified version of classification tree, is an ensemble classifier which comprises of many individual trees applying the random forest algorithm for the purpose of regression and classification (Breiman 2001). Data mining and machine learning algorithm such as high-performance commercial Classification and Regression Trees, Random Forest, TreeNet, and Multivariate Adaptive Regression Splines are used in generation of ensemble model (Kandel et al. 2015). Results showed that random forest is the best technique which has the highest prediction accuracy (Mi et al. 2017).

Model's predictability is dependent on the selection of appropriate model, suitable parameters, and appropriate sample size of occurrence data for accomplishing the required study (Anderson and Gonzalez Jr 2011). SDM has a wide range of applications including but not restricted to spatial modeling of disasters such as landslide, flood, earthquake, etc. (Chen et al. 2017). Other arena of subject ranges from forestry (Gill et al. 2017) to wildlife where habitat of various endangered or threatened species can be identified. Researchers have used this model to assess the habitat suitability of distinct species such as Africanized honeybee (Gill and Sangermano 2016a, b) and Andean cat distribution (Marino et al., 2011), etc.

Panthera Tigris's habitat can be predicted by assessing various parameters essential for its survival such as topographical, climate, human disturbance and availability of prey etc. Most of the peer-reviewed papers of tiger's habitat suitability modeling has used generally vegetation density, availability of water source, slope, aspect, different land use/land cover types, and human disturbance factors such as nearness of settlements, road networks, and railway tracks from the habitat range of the species, whereas availability of sufficient amount of food is the basic requirement for the sustenance of the species. Deer, sambar deer, chital, goral, and nilgai acted as major prey for the top predator *Panthera tigris* (Dash et al. 2015; Singh et al. 2009). There are various studies that have been done on the *Panthera tigris* habitat suitability in India, whereas only few studies have been done for the Rajaji Tiger Reserve. Researches which are undertaken in Uttarakhand (Singh et al. 2009) evaluated the suitability of tiger's habitat in Jim Corbett National Park using remote sensing and GIS along with multi-criteria analysis. Results showed that 51.4% area is highly suitable, whereas 31% of the region is moderately suitable. Kanagaraj et al. (2011) have attempted to assess the habitat suitability for tiger in "fragmented Terai Arc Landscape." Rajaji National Park also falls in this study area. They have used ENFA and GLM for prediction. Results conveyed that 24% (18,500 km^2) area are predicted to be suitable. Rajaji-Corbett corridor is also predicted to be suitable according to their analysis. No such studies for the RTR have been done which includes the use of climatic variables along with the techniques such as Maxent and Bioclim. Present study aims to identify suitable habitat for *Panthera tigris* using three presence-only species distribution model at two grain size (30,900 m) and to develop an ensemble model for habitat suitability of *Panthera tigris* at two grain size (30,900 m).

Rajaji Tiger Reserve (RTR), part of RNP, holds the great potential to sustain a large number of tigers; therefore, evaluation of habitat suitability is important. Various techniques are available for habitat suitability modeling (Farashi and Erfani 2018). Each technique has its own strength and weakness, and therefore it is important to investigate the habitat suitability using multiple techniques and generate a combined model for improved prediction. Present study attempts to analyze the suitable habitat zones for tigers focusing on the three ranges – Chilla, Motichur, and Gohri – of Rajaji Tiger Reserve.

19.2 Study Area

Chilla, Gohri, and Motichur ranges of Rajaji Tiger Reserve (RTR) spread in the Haridwar, Pauri Garhwal, and Dehradun districts of Uttarakhand, India (Fig. 19.1), and are situated at 280 43″ N to 310 27″ N–770 34″E to 810 02″E surrounded by the magnificent Himalayas and Shivalik to the north. Park is surrounded by river Yamuna and Ganges to the west and east direction, respectively. Climate of the reserve varies between subtropical in the plains and temperate in the hilly area. The minimum temperature ranges above freezing point, whereas maximum temperature reported to be 46 °C in May and June in the southern slope of Shivalik and plain areas of Chilla and Gohri ranges with annual precipitation ranges between 1000 and 2500 mm (Harihar et al. 2009). Elevation falls between 800 and 4500 masl. The ecosystem of the area represents several distinct zones of vegetation and forest types. Sal (*Shorea robusta*) covers the majority of the area, whereas species of riverine forests, broadleaf and mixed forest, scrubland and grassy pasture land, and subtropical pine forests are the other dominant plant species. The RTR serves as a habitat for a wide number of flora and fauna with 23 species of mammals and 315 avifauna species (Tiwari and Joshi 1997). Asian elephants (*Elephas maximus*) and royal Bengal tiger (*Panthera tigris*) are also found in the study area.

Agriculture around the area acts as a disturbance source for *Panthera tigris* habitat as the area is inhibited by a large number of human settlements. National highway segments such as Haridwar-Bijnor NH of 17 km; Haridwar-Dehradun NH

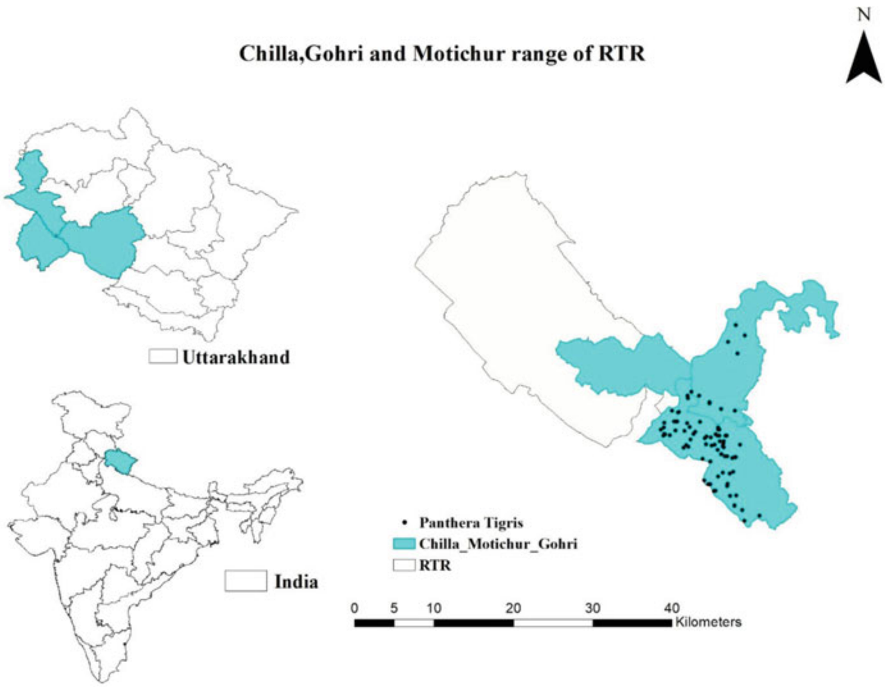


Fig. 19.1 Map of study area

of 3 and 9 km; Haridwar-Rishikesh NH of 3, 1, and 2.5 km; Dehradun-Delhi NH of 14 km; and Rishikesh-Dehradun NH of 6 km are parts of the area. Haridwar-Dehradun and Haridwar-Rishikesh rail tracks are the main hindrance to the habitat.

19.3 Database and Methodology

Sample size of 295 presence location (*Panthera tigris*) has been used for habitat suitability modeling. Bioclim datasets have been obtained from the Global Biodiversity Information Facility (http://www.worldclim.org/bioclim). Datasets have been partitioned by randomly sampling the data into 60% to train the model and remaining 40% to test the models. Surveying and collection of data were made in 2004–2017. Global digital elevation model data of 1 arc second (30 m) was used to extract the slope and elevation. Waterbody, roads, and railway tracks vector layers have been downloaded for the whole India from OSM. Atmospherically corrected surface reflectance data from Landsat 7 ETM+ sensor, Landsat 5 TM sensor, and Landsat 8 OLI/TIRS sensors were obtained from Google Earth Engine, and further analysis has been performed. The imagery has been taken for two seasons, i.e., between March and May from 2004 to 2017 and between October and November from 2004 to 2017. Bioclimatic layers have been generated from the monthly temperature and rainfall data, derived to produce more biologically meaningful variables. This dataset is widely used by ecologists, researchers, and scientist in order to build species distribution model and related ecological niche models (Booth et al. 2014). Layers reflect the annual trends such as mean annual temperature, annual precipitation, etc., seasonality (e.g., annual range in temperature and precipitation), and extreme environmental factors such as temperature of the coldest and warmest month and precipitation of the dry and wet quarters. Details of the bioclimatic variables are reported in Table 19.1.

ArcGIS 10.5 software was used for the preparation of environmental variables, map preparation, and generation of ensemble model. The TerrSet was used for the preparation of EGV for ENFA Statistical Analysis. Google Earth Engine was used for the preparation of NDVI time series analysis. Maxent version 3.3.3 was used for Maxent species distribution modeling. Biomapper 3 was used for ENFA modeling, and DIVA-GIS was used for Bioclim modeling.

The present study used three SDM techniques, i.e., Maxent, ENFA, and Bioclim, based on presence-only data for *Panthera tigris*. Presence data and environment variables related to topography, human disturbance, distance from resources, and constraint and bioclimatic variables were used in developing habitat suitability model. The presence of PT is considered as an independent variable, whereas input parameters were considered as dependent variables. SDM was built at finer and coarser resolution, i.e., 30 and 900 m, respectively. A total of 29 input parameters were selected. PCA was performed over the highly correlated bioclimatic variable to remove the data redundancy. There is no evaluation on PT at RTR; therefore, on the basis of difference in ROC, comparison has been made among the habitat suitability model developed by Maxent by including, excluding, and compressing the bioclimatic variables at 900 m grain size. Figure 19.2 details the overall methodology of this study.

19.3.1 Preparation of Environmental Predictors

Environment variables which influence the *Panthera tigris* habitat were selected on the basis of ecologically relevant factors as per published literature. Topographical, climatic, and human disturbance factors were selected for predicting the suitable habitat for *Panthera tigris*. A total of 29 input parameters, namely, NDVI, distance from road, railway tracks, settlements, water resources, slope, and elevation, and 19 bioclimatic variables were selected.

NDVI is used as a proxy of forest density where mean and standard deviation value of NDVI represents the overall mean vegetation productivity and seasonal vegetation productivity, respectively. Mean and standard deviation NDVI for two seasons (March–May and October–November) for the time period of 2004–2017 was calculated using Google Earth Engine. A simple JavaScript was used for the computation of NDVI. Afterwards TerrSet's TSTAT has been used to prepare the mean and standard deviation of the NDVI image (Jensen 2000).

Table 19.1 Bioclimatic variable and environment variables used in the study

S. No.	Bioclimatic layers/environment variables	Source	Spatial resolution (m)
BIO1	Annual mean temperature	WorldClim data	900
BIO2	Mean diurnal range (mean of monthly (max temp - min temp))	WorldClim data	900
BIO3	Isothermality (BIO2/BIO7) (* 100)	WorldClim data	900
BIO4	Temperature seasonality (standard deviation *100)	WorldClim data	900
BIO5	Maximum temperature of warmest month	WorldClim data	900
BIO6	Minimum temperature of coldest month	WorldClim data	900
BIO7	Temperature annual range (BIO5-BIO6)	WorldClim data	900
BIO8	Mean temperature of wettest quarter	WorldClim data	900
BIO9	Mean temperature of driest quarter	WorldClim data	900
BIO10	Mean temperature of warmest quarter	WorldClim data	900
BIO11	Mean temperature of coldest quarter	WorldClim data	900
BIO12	Annual precipitation	WorldClim data	900
BIO13	Precipitation of wettest month	WorldClim data	900
BIO14	Precipitation of driest month	WorldClim data	900
BIO15	Precipitation seasonality (coefficient of variation)	WorldClim data	900
BIO16	Precipitation of wettest quarter	WorldClim data	900
BIO17	Precipitation of driest quarter	WorldClim data	900
BIO18	Precipitation of warmest quarter	WorldClim data	900
BIO19	Precipitation of coldest quarter	WorldClim data	900
ENV1	NDVI mean (March–May)	Landsat 5,7,8	30
ENV2	NDVI standard deviation (March–May)	Landsat 5,7,8	30
ENV3	NDVI mean (October–November)	Landsat 5,7,8	30
ENV4	NDVI standard deviation (October–November)	Landsat 5,7,8	30
ENV5	Slope percentage	SRTM	30
ENV6	Elevation (m)	SRTM	30
ENV7	Distance from water source	OpenStreetMap (OSM)	30
ENV8	Distance from road	OpenStreetMap (OSM)	30
ENV9	Distance from railway track	OpenStreetMap (OSM)	30
ENV10	Distance from settlement	Google Earth	30
ENV11	Climate data (PC1)	WorldClim	30

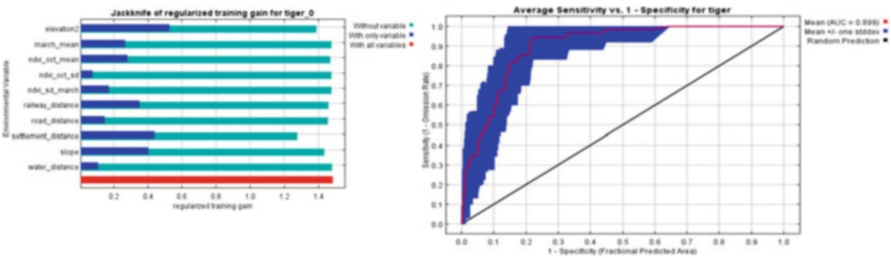


Fig. 19.2 Methodological framework

$$\mathrm{NDVI} = \frac{\mathrm{NIR} - \mathrm{RED}}{\mathrm{NIR} + \mathrm{RED}}$$

SRTM DEM (30 m) has been extracted by mosaicking the two tiles, and subset has been created according to the study area's shapefile. Therefore, sink has been filled for removing the partial redundancy in DEM and used for the preparation of slope percentage through slope tool (Spatial Analyst) available in ArcGIS. Road, railway tracks, and waterbody vector layer were taken from OpenStreetMap (OSM) for the whole India (OpenStreetMap contributors 2015). Datasets pertaining to the study area were extracted by clipping, merging, and sub-setting the vector layer. Since road and railway tracks act as disturbance in the movement of the tiger, Euclidean distance from road and railway tracks was calculated. Source of water as distance from waterbody was also calculated. Nearness to the water source is a favorable indicator, whereas the rest of all variables of distance acted as a disturbance factor. Settlement layer, a disturbance source, was extracted by manually digitizing the polygons on Google Earth. Preprocessing was made by converting KML layer into shapefile using a conversion tool in ArcGIS.

The same dataset was processed in two different spatial resolutions, i.e., moderate (30 m) and coarse (900 m). In addition to the abovementioned variables, 900 m resolution datasets included 19 bioclimatic variables as well. These bioclimatic variables include annual mean temperature, mean diurnal range (mean of monthly (max temp - min temp)), isothermality (BIO2/BIO7) (* 100), temperature seasonality (standard deviation *100), max temperature of warmest month, min temperature of coldest month, temperature annual range (BIO5-BIO6), mean temperature of wettest quarter, mean temperature of driest quarter, mean temperature of warmest quarter, mean temperature of coldest quarter, annual precipitation, precipitation of wettest month, precipitation of driest month, precipitation seasonality (coefficient of variation), precipitation of wettest quarter, precipitation of driest quarter, precipitation of warmest quarter, and precipitation of coldest quarter. These climatic layers were downloaded from the WorldClim (http://www.worldclim.org/) which provides free continent level climatic datasets at the 900 m spatial resolution for ecological modeling. Data were clipped to the extent of the study area in ArcGIS. These climatic variables were used in their original spatial resolution, whereas the remaining environmental variables were aggregated.

19.4 Data Standardization and Species Distribution Modeling

Species distribution modeling (SDM) has the prerequisite to accept the data which has the same spatial resolution and cell size, i.e., number of rows and column, and the same geographical extent. A mask layer was prepared in ArcGIS where all the remaining layers were extracted by using this mask. This process transfers the same spatial resolution, cell size, and geographic location to all the variables. Three SDMs were used for the analysis. While Bioclim is a classical approach (the first SDM model), the other two – Maxent and ENFA – are a much advanced approach for SDM. SDM models are sensitive to the use of multicollinearity of the environment variables, and therefore redundancy among the variables needed to be removed. Multicollinearity is a state when independent variables are correlated to each other (Cruz-Cardenas et al. 2014). Except for the climatic variables, all the variables were chosen on the basis of strong ecological importance. Since there do not exist any study for *Panthera tigris* habitat which discusses the important climatic variables, all the 19 variables were used in the study. Since these variables were strongly correlated, principal component analysis (PCA) was performed on the variables using the TerrSet software. PCA is a data reduction technique used in digital image processing which reduces the datasets into few uncorrelated principal components where first principal component shows the maximum information which contains the maximum variance, and subsequently the remaining information will be showed by other principal components.

19.4.1 Maxent

Maxent, a non-parametric technique, is a general purpose machine learning algorithm and makes prediction on the basis of environmental covariates for the data on presence locations (Phillips et al. 2006). Maxent accepts the presence data in the form of x and y coordinates where x is the longitude and y is the latitude which should be the same as the coordinate system of environment variables. Maxent software is used in the present study with a sample size of 297 for presence data obtained from Global Biodiversity Information Facility (GBIF). The first principal component explaining 99% variance for 19 bioclimatic variables was chosen as an environmental variable. Maxent software accepts the environment variables in ASCII format and presence data in .csv format (species name, x, y). All the environment variables were first re-projected to Geographic coordinates system from the projected coordinate system as presence data were in the form of degree decimal (geographic coordinates). Raster to ASCII conversion tool in ArcGIS was used to convert the raster data into ASCII format with same spatial resolution, cell size, extent, and coordinate system. Maxent model was run on two sets of input variable of different spatial resolution. Maxent has the ability to run the model multiple times and then average the results obtained from all the Maxent model. In this study, model was run 15 times with 5000 iterations so that convergence threshold could be attained. Maximum training sensitivity plus specificity threshold was applied to obtain the logistic output which maximizes the sum of sensitivity and specificity (Kramer-Schadt et al. 2013). Values above this threshold were considered presence whereas absence for the values falling below the threshold. Also, the model was affected by the sample bias, so a bias file along with the sampling area has been created which significantly reduces the sample biasness. Test file which is the presence data for testing the model was used for model validation. In order to prevent the model overfitting, default regularization 1 was used which checks the gain value and makes sure that presence data doesn't fit the presence data too tightly. Finally, it provides logistic output with values ranging from 0 to 1 where 0 is the lowest probability of occurrence and 1 being the highest. Receiver Operating Characteristic (ROC) or area under curve (AUC) (Fielding and Bell 1997) was used for presence-only model evaluation (Phillips et al. 2006). ROC values range between 0 and 1 where values higher than 0.5 show better prediction ability in comparison to 0.5 which doesn't discriminate between the available habitat and the used habitat.

19.4.2 Ecological Niche Factor Analysis (ENFA)

ENFA is a presence-only SDM method which is based on simple multivariate statistics. The working principle of the model is similar to that of PCA. ENFA summarizes the variables into few uncorrelated ecologically relevant factors and computes the suitability function by comparing environmental variable values of species presence cells with respective mean, median, and geometric values of the entire study area based on eigenvalues and eigenvectors (Farashi et al. 2013).

ENFA is based on the three conceptions, i.e., marginality, specificity, and tolerance, as defined below.

$$\text{Marginality,}\quad M = \frac{\left|m_g - m_s\right|}{1.96\sigma_G}$$

$$\text{Specialization,}\quad S = \frac{\sigma_G}{\sigma_S}$$

$$\text{Tolerance,}\quad T = \frac{1}{S}$$

where mG = mean of the EGV in the whole study areas, σ_G = standard deviation of the global distribution, m_S = mean of the EGV of the focal species distribution, and S σ = standard deviation of the focal species distribution.

Marginality can be defined as the ecological distance between the species optimum and mean habitat (Tsoar et al. 2007). Specialization depicts the ratio of ecological variance of the mean habitat to that of the focal species. In this study, Biomapper version 3 was used for performing ENFA. It started with the preparation of presence data into raster formatted boolean data of 0 and 1 where 0 represents the absence and 1 represents the species presence cells. Tiger presence points have been converted into IDRISI formatted Boolean raster which depicts the presence and absence data. All the environment variables were converted from tiff format to IDRISI's rst format. After making sure that its resolution, cell size, and extent are all same, all the environment variables were imported as an ecogeographical variable (EGV) into Biomapper which should be overlayable to each other. The discrepancies in all EGV layers were masked to a study area mask which is a Boolean map of 0 and 1. After that −999 should be assigned as a background value to all the EGV. Consistencies of the EGV can be checked by verifying them. Model was run on the untransformed original EGV, and covariance and correlation matrix have been computed for the EGV. Finally, factors have been computed using ENFA technique. Factor has been selected by "broken stick advice" which is the distribution of the eigenvalue as compared to the distribution of MacArthur's broken stick (Segurado and Araujo 2004). It is the expected distribution when breaking a stick randomly. Therefore, the eigenvalues that are larger than what would have been obtained randomly may be considered "significant." Finally, habitat suitability map has been computed by including the ecologically relevant factors. Model has been validated using the jackknife cross-validation process (Xuezhi et al. 2008) which randomly portioned the presence data into ten subsets of equal part where nine subsets were used for the calibration of habitat suitability map and last one was used for the model's validation. This process has been replicated ten times such that each subset was used for validation purpose. Absolute value index (AVI) was generated which shows the percentage of predicted suitability exceeding the 0.5 of the validation cells. Mean and variance of AVI are used as an accuracy assessment of the model.

19.4.3 Bioclim

Bioclim is a bioclimatic envelope model and is a correlative model that utilizes the association between occurrence data and climatic variables in order to define the sets of climatic conditions under which species maintain their habitat (Ackerly et al. 2010). SDM generated by Bioclim is based on the concept of intersecting the ranges by the species along individual environmental axis (Booth 2018). Results show that Bioclim develops SDMs by intersecting the ranges inhabited by the species along each environmental axis. An advantage of this method is that results are entirely transparent for interpretation (Booth 2018). DIVA-GIS is used in order to generate SDM from input variables and presence data. The process allows to break the data randomly into testing and training. Present study considered 60% data for training and 40% data for testing. As there is no absence data, random pseudo absence point has been generated by the DIVA-GIS. ROC curve is generated in order to test the model's accuracy.

19.4.4 Ensemble Model

Ensemble model was built using only models which had accuracy higher than 70% as per ROC. Ensemble model is generated using weighted linear combination of the selected models because most of the literature cited that it has the highest predictive performance (Roeland 2018). Maxent and ENFA models were used in the preparation of ensemble model as both models achieved accuracy higher than 0.7. The weights for these models are calculated by subtracting AUC value from 0.5 where AUC value of 0.5 is the definition for random model. Model with AUC values between 0.5 and 0.7 are low performer; between 0.7 and 0.9 are moderate performer; and > 0.9 are high performer (Manel et al. 2001). Maxent version 3 is used for the calculation of ROC values for Maxent algorithm, whereas ROC module of IDRISI Selva software is used to calculate the values for ENFA. ENFA shows the prediction value between 0 and 100 percentage as 0 showing the least and 100 showing the maximum likelihood of occurrence of the individual of species under consideration. IDRISI's stretch module has been used for the purpose of linear stretching. Prediction value for all the models ranges between 0 and 1. ArcGIS's raster calculator has been used to perform all the calculations afterwards.

19.5 Results

The habitat suitability mapping for *Panthera tigris* was carried out using three different presence-only SDM models at two grain sizes of 30 meter and 900 meter. Since SDM approaches are sensitive to multicollinearity of the predictors, PCA was performed on 19 bioclimatic variables (900-meter grain size) (Table 19.2). Principal component 1 explained 99.97% of the variance and was found to have strong correlation (above 0.99: Table 19.3) with all the variables.

Table 19.2 Habitat suitable and unsuitable area according to different SDM techniques

SDM	Grain size (m)	Suitable area (km^2)	Unsuitable area (km^2)	Total area (km^2)
Maxent	30	58	277	335
Maxent	900	78	257	335
ENFA	30	89	246	335
ENFA	900	74	261	335
Bioclim	30	42	295	335
Bioclim	900	51	284	335
Ensemble	30	105	230	335
Ensemble	900	96	239	335

Table 19.3 Principal components with percent variance explained and correlation between original variables and components

T-mode component	C 1	C 2	C 3	C 4	C 5	C 6	C 7
% Var.	99.78	0.13	0.08	0.001	0	0	0
T-mode loading	C 1	C 2	C 3	C 4	C 5	C 6	C 7
1bio	0.98	−0.16	0.1	0	0	0	0
2bio	0.99	−0.01	−0.02	0	0	0	0
3bio	0.99	−0.01	−0.02	0	0	0	0
4bio	0.99	−0.02	−0.02	0	0	0	0
5bio	0.99	−0.01	−0.02	0	0	0	0
6bio	0.99	−0.01	−0.02	0	0	0	0
7bio	0.99	−0.01	−0.02	0	0	0	0
8bio	0.99	−0.01	−0.02	0	0	0	0
9bio	0.99	−0.01	−0.02	0	0	0	0
10bio	0.99	−0.01	−0.02	0	0	0	0
11bio	0.99	−0.01	−0.02	0	0	0	0
12bio	0.99	0.02	0.01	0	0	0	0
13bio	0.99	0.01	0	0	0	0	0
14bio	0.99	−0.01	−0.02	0	0	0	0
15bio	0.99	−0.01	−0.01	0	0	0	0
16bio	0.99	0.03	0.02	0	0	0	0
17bio	0.99	−0.01	−0.02	0	0	0	0
18bio	0.99	0.01	0	0	0	0	0
19bio	0.99	−0.01	−0.02	0	0	0	0

Therefore, first principal component was appropriate and selected for the description of geography with respect to 19 variables. Result of ensemble model shows that out of the 335 km^2 area, only 105 km^2 was suitable, whereas 230 km^2 area was unsuitable at 30 m grain size; however, 96 km^2 was suitable, and 239 km^2 area was unsuitable at 900 m grain size.

19.5.1 Maxent at 30 m Grain Size

The Maxent model was run at two grain size: 30 and 900 m. A total of ten environment variables were used in the 30-meter grain size (Table 19.3). Jackknife graph of variable importance shows the training gain of each variable if the model was run in isolation and compares it to the training gain with all other variables (Fig. 19.3). The values showing here are the average of replicate runs. Figure 19.4 shows that elevation layer has contributed the most in predicting *Panthera tigris* habitat in comparison to the SD NDVI (October–November) same in the test gain shown in Annexure 1 section which shows the elevation has a considerable contribution in both the training and test samples. The environmental variable that

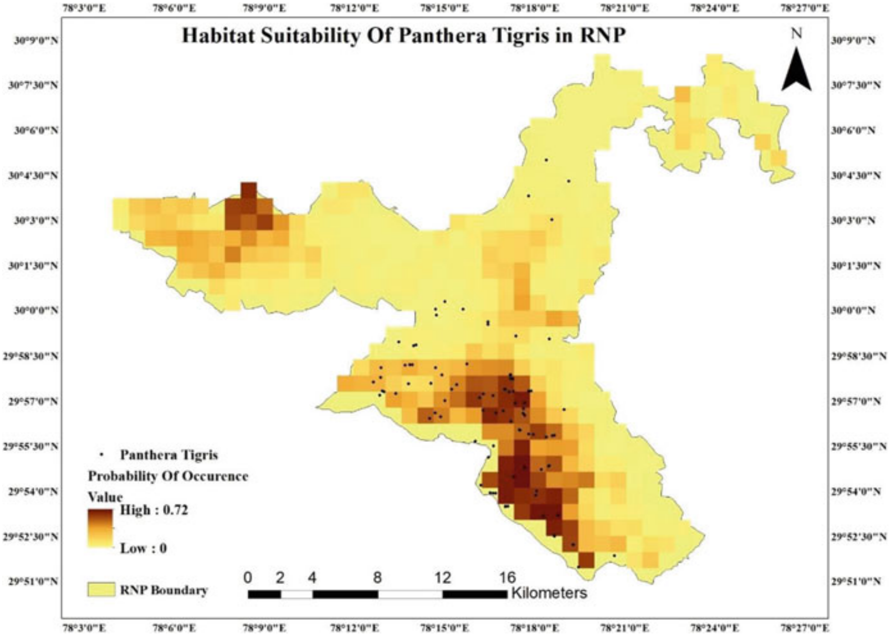


Fig. 19.3 Principal component analysis (PC1)

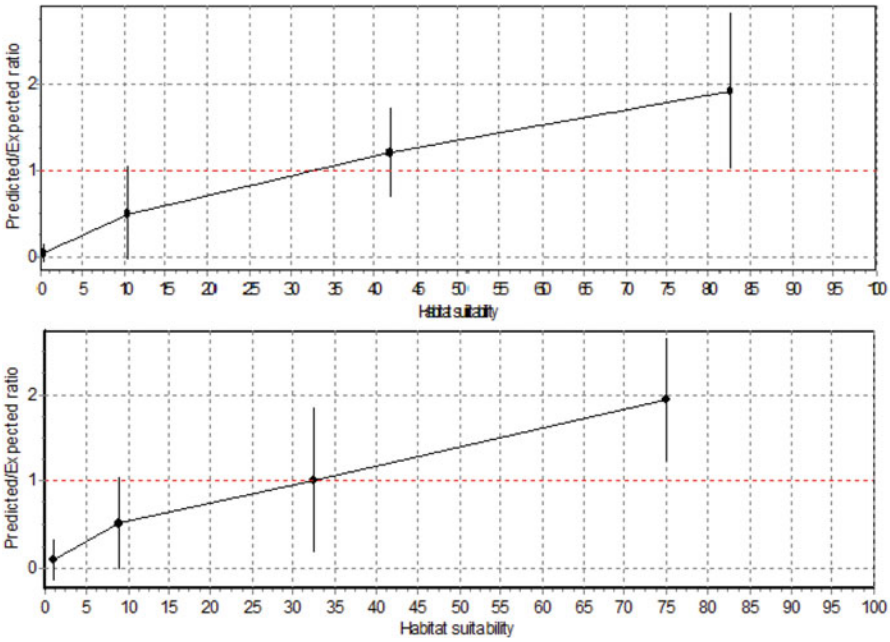
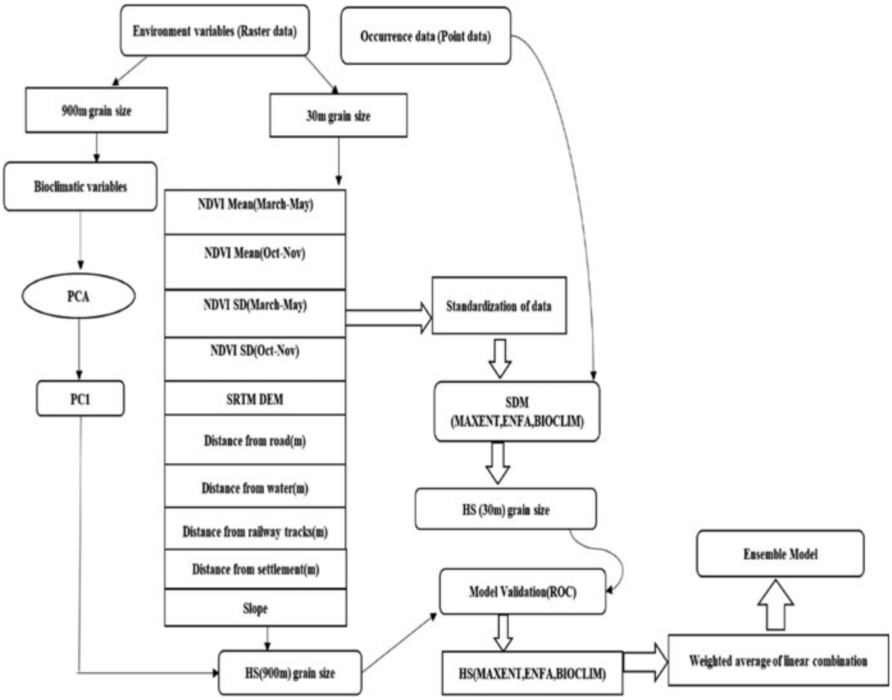


Fig. 19.4 Jackknife of regularized training gain for Panthera tigris and ROC for 30 m grain size Maxent model



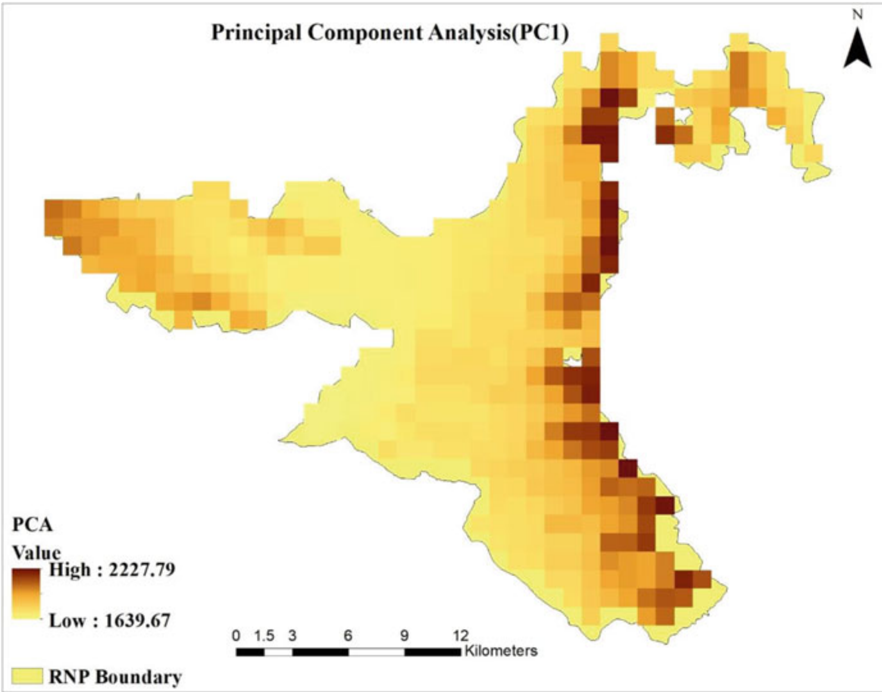
Annexure 1 Jackknife of regularized test gain for Panthera tigris at 30 m grain size Maxent

decreases the gain the most when it is omitted is distance from settlement, which therefore appears to have the most information that isn't present in the other variables both in training and testing samples. Lastly Annexure 2 shows the same jackknife test, using AUC on test data.

Figure 19.5 is the receiver operating characteristic (ROC) curve for the same data, again averaged over the replicate runs. The specificity is defined using predicted area, rather than true commission. The average test AUC for the replicate run is 0.89, and the standard deviation is 0.055. ROC value 0.89 indicates that the model's performance is better than random. The closer the value is to 1, the better the model has performed, where 0.5 indicates model no better than random. This indicates that the model has predicted the *Panthera tigris* habitat with more than 89% spatial accuracy.

The test omission rate and predicted area as a function of the cumulative threshold averaged over the replicate runs (Annexure 3). The omission rate should be close to the predicted omission because of the definition of the cumulative threshold. The orange and blue shading surrounding the lines on the graph represents variability. Figure 19.6 shows the habitat suitability map which predicts 58 km^2 area to be suitable and 277 km^2 to be unsuitable from the total area of 335 km^2.

Table 19.4 shows estimates of relative contributions of the environmental variables to the Maxent model. For determining the first estimate, in each iteration of the



Annexure 2 Jackknife of AUC for Panthera tigris at 30 m grain size Maxent

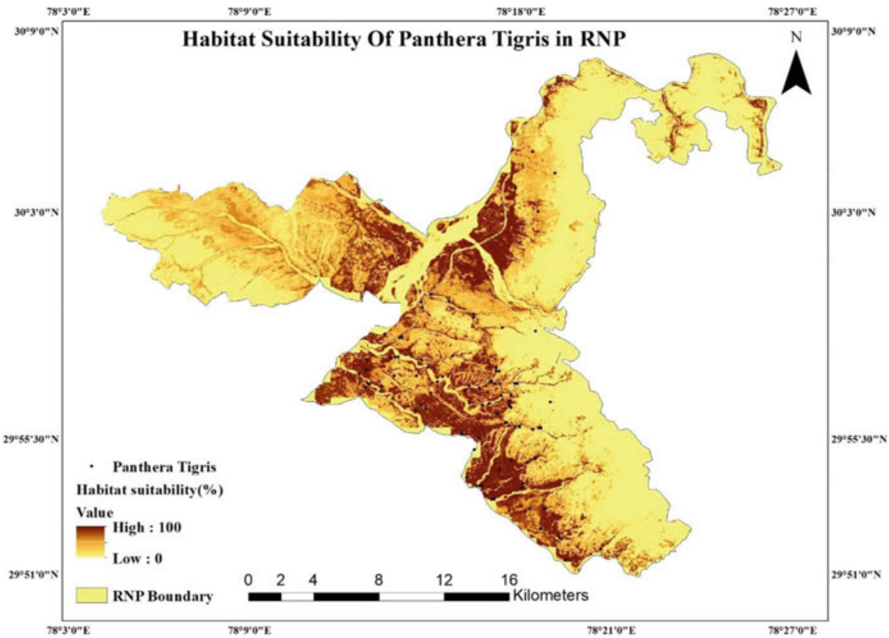
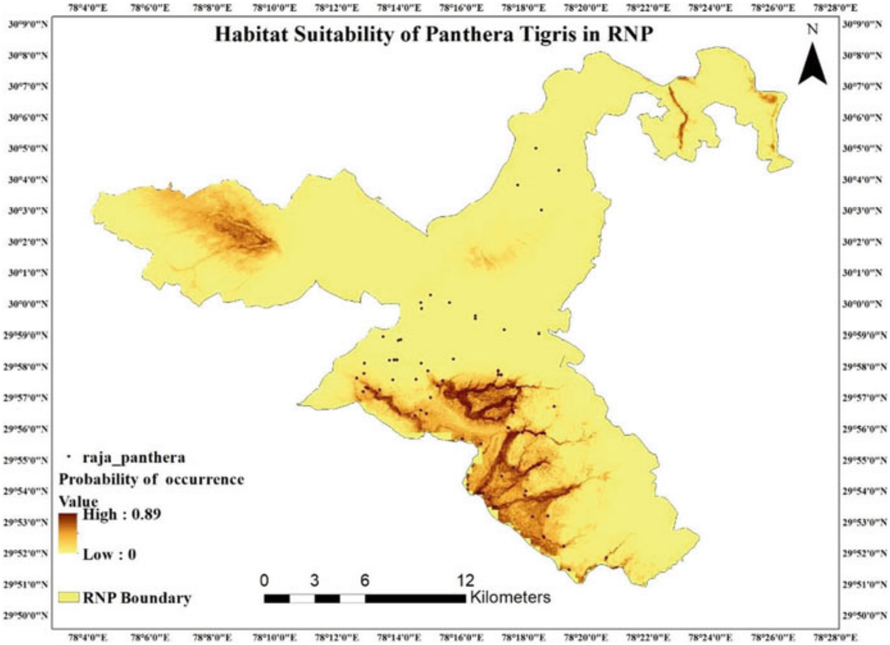


Fig. 19.5 Map showing habitat suitability of Panthera tigris using Maxent at 30 m grain size



Annexure 3 Average omission and predicted area for Panthera tigris of 30 m grain size

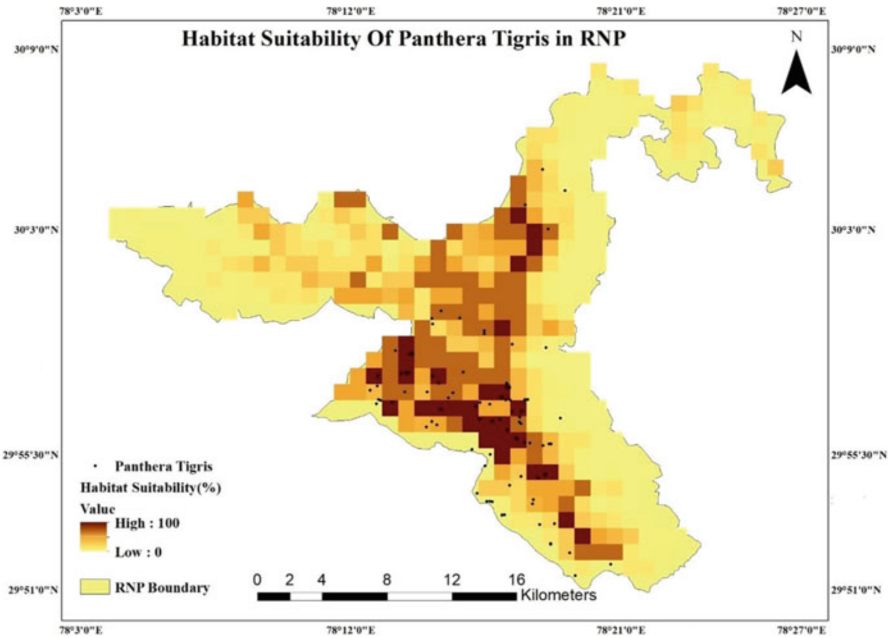


Fig. 19.6 Response curves

Table 19.4 Percentage contribution of variables

Variable	Percent contribution	Permutation importance
Distance from settlements	38.4	48.1
Slope	20.3	12.6
Elevation	19.6	26.6
Mean NDVI (for the month of October)	7.7	1.9
Distance from railway tracks	4.3	5.1
Distance from waterbodies	4.3	1.2
Distance from road	4.3	2.8
Standard deviation from NDVI (for the month of October)	0.6	1.5
Mean NDVI (for the month of March)	0.3	0.1
Standard deviation from NDVI (for the month of March)	0.3	0.2

training algorithm, the increase in regularized gain is added to the contribution of the corresponding variable or subtracted from it if the change to the absolute value of lambda is negative. Similarly, for the second estimate, for each environmental variable in turn, the values of that variable on training presence and background data are randomly permuted. The model is reevaluated on the permuted data, and the resulting drop in training AUC is shown in Table 19.4, normalized to percentages. As with the variable jackknife, variable contributions should be interpreted with caution when the predictor variables are correlated. As evident from Table 19.4, the percent contributions of the different environmental variables vary. But distance from settlements which denotes the human influence accounts for 38.4% of the factor responsible for tiger distribution. Apart from distance from road, slope, and elevation, NDVI mean (October–November) which is a proxy of forest density also plays a significant role in the distribution of the tiger.

The response curves in Fig. 19.7 show how logistic prediction value changes by change in the environmental variables. Elevation which has the highest contribution to the gain as observed in jackknife shows higher predicted suitability values between 200 and 600 m and lesser towards 800 and 1400 m. Distance from settlement has higher values of predicted suitability at around 4000–15,660 m and lower towards 0–3999 m which is making sense that nearer distance is not a suitable habitat, whereas farther distance shows the suitability. The same trend is showing for the distance from railways and road. However, mean NDVI of October–November has higher values from 0.38 to 0.837 which shows that higher density of forest or dense forest areas contributes in the suitable habitat. Observing the distance from water, 0–800 m are showing higher values of predicted suitability, whereas 900–2684.12 m are showing lesser suitability meaning source of water plays an important role in habitat suitability; they prefer the area surrounding waterbody. Lower percentage of slope values shows the higher predicted suitability and vice versa.

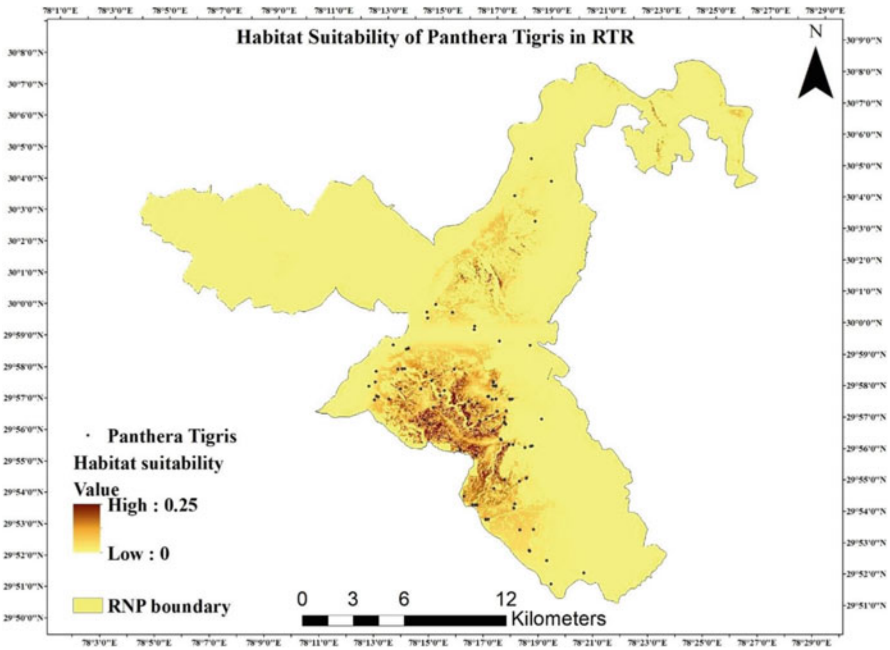


Fig. 19.7 Jackknife of regularized training gain for Panthera tigris at 900 m grain size Maxent model and ROC for 900 m grain size Maxent model

19.5.2 Maxent at 900 m Grain Size

A total of 11 environmental variables at spatial resolution of 900 m have been used in prediction of habitat suitability for *Panthera tigris* using Maxent technique. This model also has the inclusion of climatic variables which will also provide the information that how the suitability of PT is influenced by climatic variables. The following are the results obtained. Jackknife graph of variable importance shows the training gain of each variable if the model was run in isolation and compares it to the training gain with all other variables shown in Fig. 19.8. The values showing here are the average of replicate runs. Figure 19.8 shows that the environmental variable with the highest gain when used in isolation is elevation in comparison to mean NDVI of March–May, which therefore appears to have the most useful information by itself, whereas (Annexure 4) SD NDVI (March–May) has the highest gain in testing samples. The environmental variable that decreases the gain the most when it is omitted is SD NDVI (March–May), which therefore appears to have the most information that isn't present in other variables. Values shown are averages over replicate. Lastly Annexure 5 shows the same jackknife test, using AUC on test data.

Figure 19.9 is the receiver operating characteristic (ROC) curve for the same data, again averaged over the replicate runs. The specificity is defined using predicted area, rather than true commission. The average test AUC for the replicate runs is

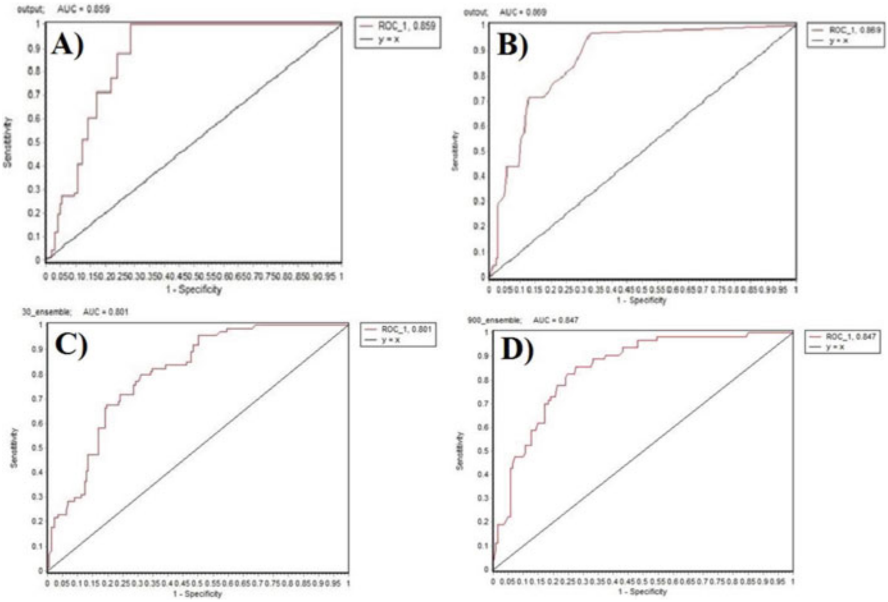
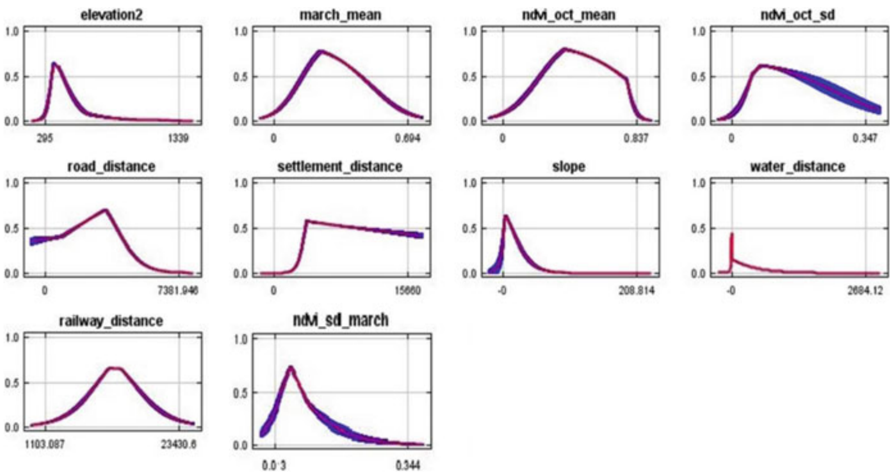
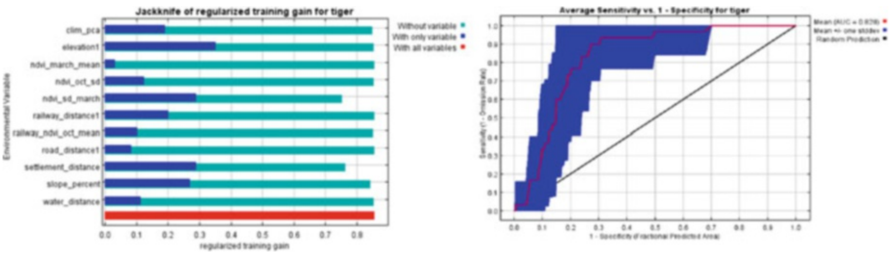


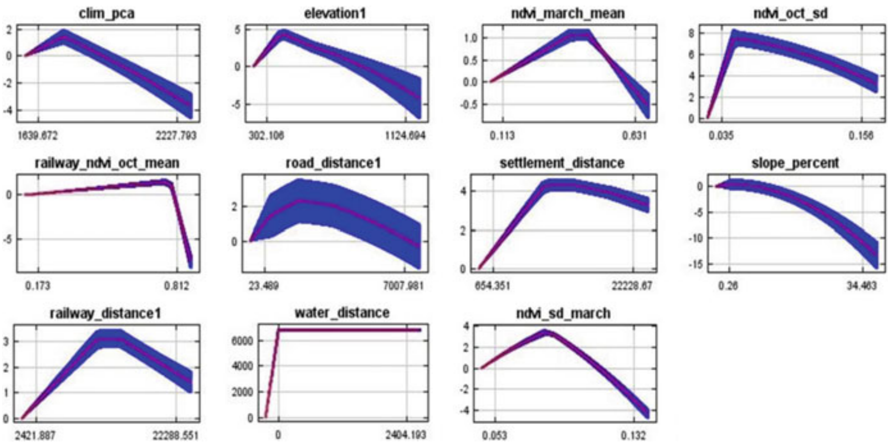
Fig. 19.8 Response curves for 900 m grain size Maxent model



Annexure 4 Jackknife of test gain for PT at 900 m grain size Maxent model



Annexure 5 Jackknife of AUC for PT at 900 m grain size Maxent model



Annexure 6 Average omission and predicted area for Panthera tigris at 900 m spatial resolution Maxent model

0.82, and the standard deviation is 0.095. ROC value of 0.82 indicates the model to be a good fit as compared to random. The closer the value is to 1, the better the model has performed, where 0.5 indicates model no better than random. This indicates that the model has predicted the *Panthera tigris* habitat with more than 82% spatial accuracy (Annexure 6).

Table 19.5 shows estimates of relative contributions of the environmental variables to the Maxent model. For determining the first estimate, in each iteration of the training algorithm, the increase in regularized gain is added to the contribution of the corresponding variable or subtracted from it if the change to the absolute value of lambda is negative. Similarly, for the second estimate, for each environmental variable in turn, the values of that variable on training presence and background data are randomly permuted. The model is reevaluated on the permuted data, and the resulting drop in training AUC is shown in Table 19.6, normalized to percentages. As with the variable jackknife, variable contributions should be interpreted with caution when the predictor variables are correlated. As evident from Table 19.6, the

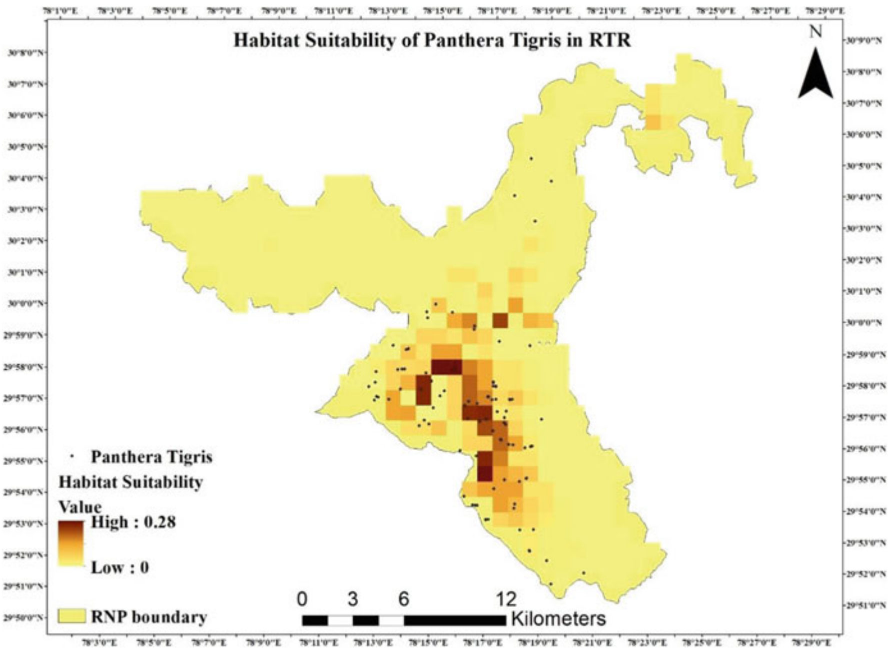


Fig. 19.9 Map showing habitat suitability of Panthera tigris using Maxent at 900 m grain size

Table 19.5 Percentage of contribution of variables at 900 m spatial resolution's Maxent model

Variable	Percent contribution	Permutation importance
Distance from settlements	40	52
Standard deviation from NDVI (for the month of March)	23.8	27.5
Elevation	15.8	3.4
Distance from waterbodies	9.6	0.4
Slope percentage	8.6	8.5
Principal component analysis of climatic variables	1.3	5.2
Mean NDVI (for the month of October)	0.5	1.5
Standard deviation from NDVI (for the month of October)	0.2	1.1
Mean NDVI (for the month of March)	0.1	0.2
Distance from road	0	0.2
Distance from railway tracks	0	0

percent contributions of different environmental variables vary. But distance from settlements which denotes the human influence accounts for 40% of the factor responsible for tiger distribution. Apart from distance from road, slope, and elevation, NDVI SD (March–May) which is a proxy of forest density also plays a significant role in the distribution of the tiger and contributes 23.8%, whereas

Table 19.6 Factors of marginality and specialization (A)

EGV	Factors of specialization				
	Factor 1 (95%) marginality	Factor 2 (4%)	Factor 3 (1%)	Factor 4 (0%)	Factor 5 (0%)
Elevation	−0.55	(Distance from water) −0.76	−0.59	−0.64	−0.59
PC1 (Bioclimatic)	−0.46	−0.46	−0.5	0.5	0.58
Slope %	−0.31	0.36	0.4	−0.36	0.37
Distance to railway	0.3	−0.17	−0.34	0.25	−0.34
NDVI SD (October–November)	−0.27	0.16	0.32	−0.17	−0.14
NDVI SD (March–May)	−0.25	−0.11	−0.12	−0.12	0.12
Distance from settlement	0.24	0.04	−0.08	0.07	−0.11
Distance to road	−0.19	0.04	0.05	0.05	−0.09
Distance to water	−0.19	0.04	0.05	0.04	0.09
NDVI mean (October–November)	0.18	−0.02	−0.05	0.01	0.05
NDVI mean (March–May)	−10	0.01	0.01	0.01	0.01

elevation, distance from water, and slope percentage also show a significant amount of variable contribution as 15.8%, 9.6%, and 8.6%, respectively. However, climatic variable which is PC1 doesn't show contributing much, i.e., 1.3%. This gives that climatic condition in the study area is ideal for tiger's habitat and doesn't affect the tiger's habitat unless there is climate change or future climate scenario.

The response curves in Fig. 19.8 show how logistic prediction value changes by change in the environmental variables. Distance from settlement which has the highest contribution to the gain as observed in percentage contribution table shows higher predicted suitability values between 8000 and 22,228.67 m and lesser towards 0–7000 m which is making sense that nearer distance is not suitable habitat, whereas farther distance shows the suitability. The same trend is showing for the distance from railways and road. However, mean NDVI of October–November has higher values from 0.38 to 0.9 which shows that higher density of forest or dense forest areas contributes in the suitable habitat. Observing the distance from water, 0–2500 m are showing higher values of predicted suitability which shows that water plays an important role in habitat suitability. Response curve for slope showing a negative trend, i.e., lower percentage of slope values, shows the higher predicted suitability and vice versa. Figure 19.12 shows the habitat suitability map predicting 78 km^2 area to be suitable and 257 km^2 area to be unsuitable out of 335 km^2 area.

19.5.3 Ecological Niche Factor Analysis at 30 m Grain Size

19.5.3.1 Score Matrix and Model Evaluation

ENFA has been performed over 10 EGV with a spatial resolution of 30 m. Climatic variables are not included in this analysis because of lower spatial resolution of 900 m. Two outputs have been generated by ENFA where the first shows the score matrix which is helpful in understanding the species relationship to its environmental predictors by explaining variables' contribution to the derived factors. The second output is a habitat suitability map of the study area. The first factor is the marginality factor, and the sign associated with it is important in interpretation, whereas it does not have any meaning associated to the specialization factor. Higher specialization value reflects the strongest contribution of the respective EGV for species specialization.

The score matrix represents the variance explained by the first five factors out of ten factors and the coefficient value of the EGV. Table 19.6 shows that the first three factors represent 100% of the variance, i.e., 89%, 12%, and 1% for the factor 1, 2, and 3, respectively. The overall marginality value of 0.698 signifies the less disparity of the core zone (study area) from the mean conditions. A low tolerance value of 0.087 shows that the species survive in narrow ranges of environmental conditions. The marginality coefficient of the factor 1 shows that the tiger prefers low elevated areas (coefficient = −0.51), flatter surface (−0.44), and large distance from railway tracks (0.21). Nearness to the settlements (0.24) is avoided as they are shy species. Coefficients of the second specialization factor show that distance to waterbody (0.91) and distance to railway tracks (0.30) contribute most to the model, whereas the third factor shows that distance from railway tracks (0.66) and slope (00.46) have the highest contribution in the model. Model's accuracy has been evaluated by using jackknife cross-validation which depicts the AVI index 0.818 + − 0.2251 showing the good performance of model's prediction shown in Fig. 19.13.

19.5.4 Habitat Suitability Analysis

Habitat suitability map has been computed by using the first two factors of eigenvalue which accounts for 99% marginality and 87% specialization shown in Table 19.6. These three factors explained the maximum information. However, the rest of the factors explained 0% variance therefore discarded and are not included in the computation of habitat suitability of the ENFA model. The model's output values range between 0 and 100% where 0 shows the unsuitability and 100 shows the highest suitability. Fig. 19.14 shows the habitat suitability map which predicted 89 km^2 area to be suitable and 246 km^2 to be unsuitable from the total area of 335 km^2.

19.5.5 ENFA at 900 m Grain Size

19.5.5.1 Score Matrix and Model Evaluation

ENFA has been performed over 11 EGVs which were chosen out of 29 EGVs. Two outputs have been generated by ENFA where the first shows the score matrix which is helpful in understanding the species relationship to its environmental predictors by explaining variables' contribution to the derived factors. The second output is a habitat suitability map of the study area. The first factor is the marginality factor, and the sign associated with it is important in interpretation, whereas it does not have any meaning associated to the specialization factor. Higher specialization value reflects the strongest contribution of the respective EGV for species specialization. The score matrix represents the variance explained by the first 5 factors out of 11 factors and the coefficient value of the EGV. Table 19.7 shows that the first three factors represent 100% of the variance, i.e., 95%, 4%, and 1% for the factor 1, 2, and 3, respectively. The overall marginality value of 0.541 signifies the less disparity of the core zone (study area) from the mean conditions. A low tolerance value of 0.042 shows that the species survive in narrow ranges of environmental conditions. The marginality coefficient of the factor 1 shows that the tiger prefers low elevated areas

Table 19.7 Factors of marginality and specialization (B)

	Factors of specialization				
	Factor 1 (87%)				
EGV	Marginality	Factor 2 (12%)	Factor 3 (1%)	Factor 4 (0%)	Factor 5 (0%)
Elevation	−0.51	0.91	0.66	0.71	0.52
NDVI mean (March–May)	−0.48	0.3	0.46	−0.57	−0.5
Slope %	−0.44	−0.19	−0.41	−0.26	−0.32
NDVI mean (October–November)	−0.35	−0.18	−0.39	−0.25	0.29
NDVI SD (March–May)	−0.28	−0.08	−0.13	−0.12	0.28
Distance to railway	0.21	−0.04	−0.08	0.11	0.28
Distance to water	−0.19	0.01	−0.06	0.1	−0.23
Distance to road	−0.14	0.01	−0.05	−0.07	−0.21
NDVI SD (October–November)	0.09	−0.01	0.03	−0.06	−0.16
Distance from settlement	0.06	0	0.01	−0.04	0.14

Table 19.8 Table showing marginality, specialization, and tolerance

Global	
Marginality	0.698
Specialization	11.494
Tolerance	0.087
Global	
Marginality	0.541
Specialization	23.962
Tolerance (1/S)	0.042

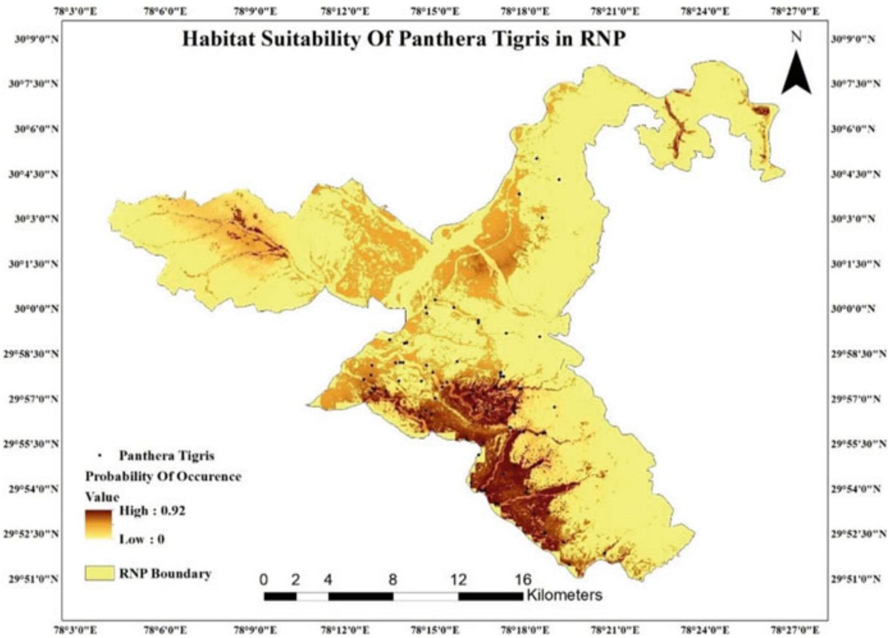


Fig. 19.10 AVI for ENFA

(coefficient = −0.55), flatter surface (−0.31), and large distance from railway tracks (0.30). Nearness to the settlements (0.24) is avoided as they are shy species. Higher density of forests (0.18) is a favorable habitat, whereas moderate climatic conditions (−0.46) are required for their survival (Table 19.8). Coefficients of two specialization factors show that distance to waterbody and distance to railway tracks contribute most to the model, whereas the three factors show that NDVI mean and NDVI SD have the highest contribution in the model. Model's accuracy has been evaluated by using jackknife cross-validation which depicts the AVI index 0.716 + −0.2 showing the good performance of model's prediction shown in Fig. 19.12.

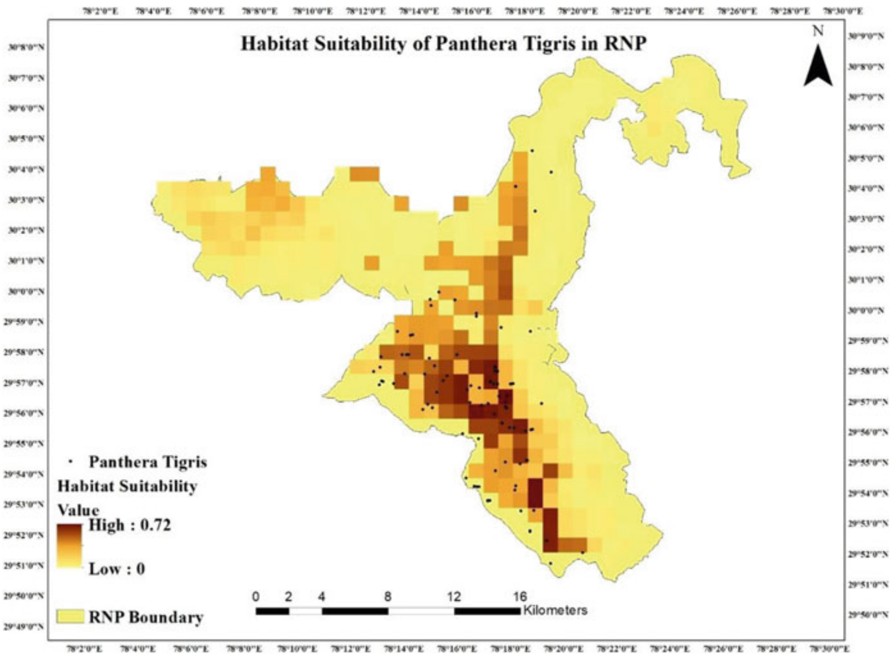


Fig. 19.11 Habitat suitability of Panthera tigris using ENFA at 30 m grain size

19.5.6 Habitat Suitability Analysis

Habitat suitability map has been computed by using the first three factors of eigenvalue which accounts for 100% marginality and 95% specialization shown in Table 19.7. These three factors explained the maximum information. However, the rest of the factors explained 0% variance therefore discarded and are not included in the computation of habitat suitability of the ENFA model. The model's output values range between 0 and 100% where 0 shows the unsuitability and 100 shows the highest suitability. Figure 19.12 shows the habitat suitability map which predicts 74 km^2 area to be suitable as compared to 261 km^2 unsuitable from the total area of 335 km^2.

19.5.7 Bioclim at 30 m Grain Size

Figure 19.13 shows the habitat suitability map of PT at 30 m grain size using the Bioclim model. Validation has been done using ROC (Fig. 19.14) which shows the 0.85 value which states that model has performed well with good accuracy. A total of

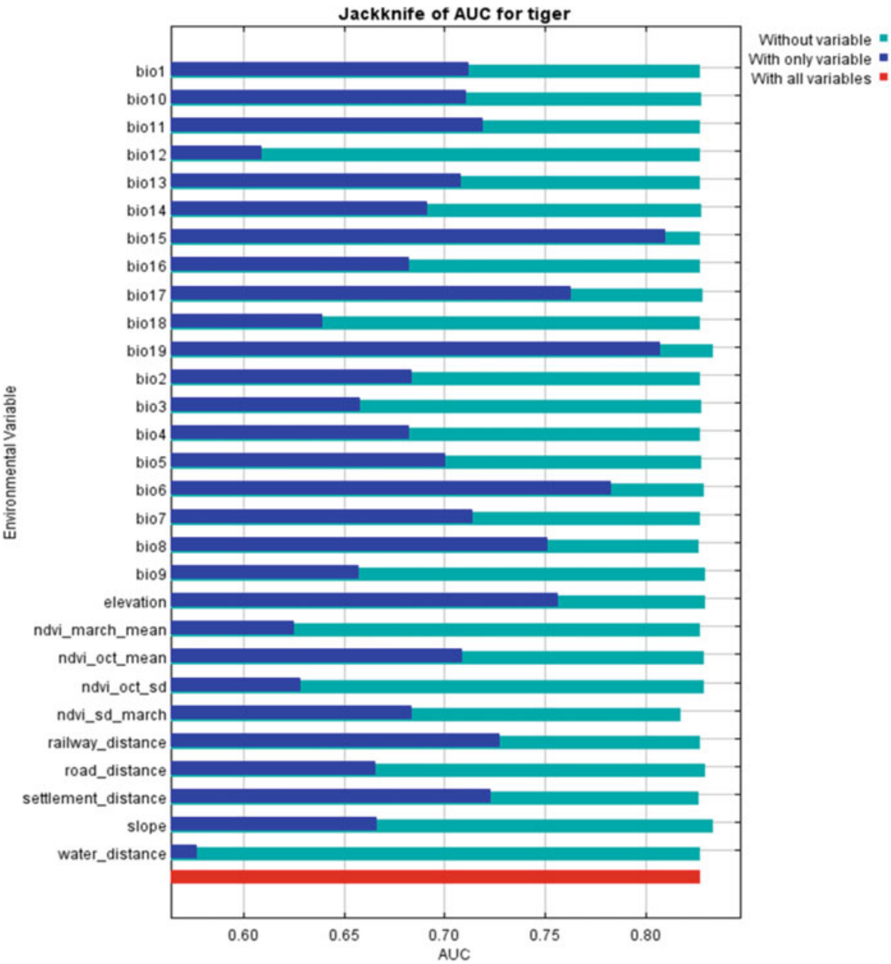


Fig. 19.12 Habitat suitability of Panthera tigris using ENFA at 900 m grain size

42 km^2 area is predicted to be suitable whereas 284 km^2 to be unsuitable out of 335 km^2 of total area.

19.5.8 Bioclim at 900 m Grain Size

Figure 19.15 shows the habitat suitability map of PT at 900 m grain size using Bioclim algorithm with 0.86 model accuracy shown by ROC (Fig. 19.14). Eastern part of RTP shows the highly suitable areas, whereas the rest of the area has low suitability. Out of 335 km^2 area, 51 km^2 is predicted to be suitable and 284 km^2 to be unsuitable.

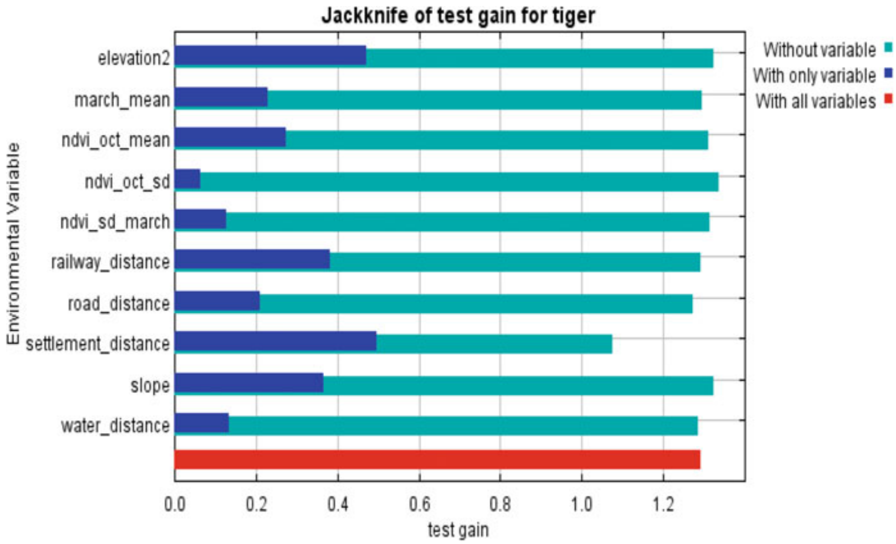


Fig. 19.13 Habitat suitability of Panthera tigris at 30 m grain size using Bioclim

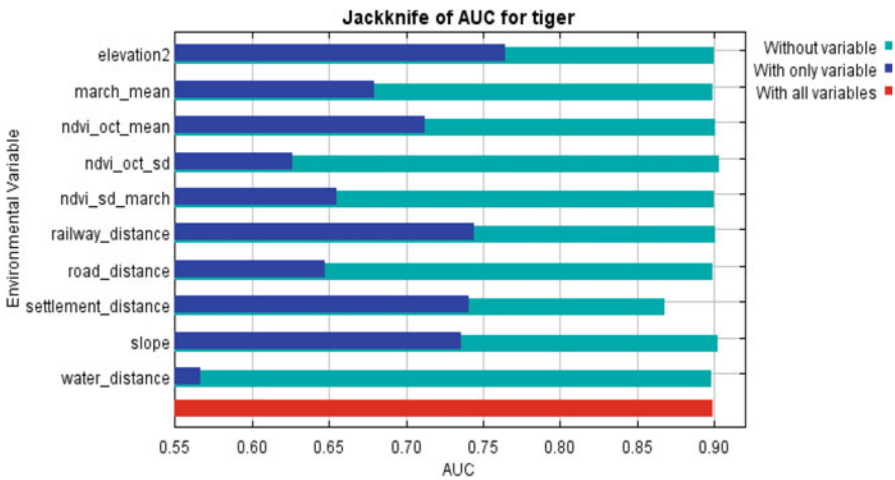


Fig. 19.14 (**a**) ROC for 30 m grain size Bioclim model; (**b**) ROC for Bioclim at 900 m grain size; (**c**) ROC of ensemble model at 30 m grain size; (**d**) ROC of ensemble model at 900 m grain size

19.5.9 Ensemble Model

Ensemble model was generated using two models, ENFA and Maxent, whose AUC value was above 0.7 for both 30 and 900 m grain size. AUC values are 0.70 and 0.71 for ENFA model both at 30 and 900 m grain size, respectively. Maxent has the AUC value of 0.89 and 0.828 at 30 and 900 m grain size, respectively. The result from

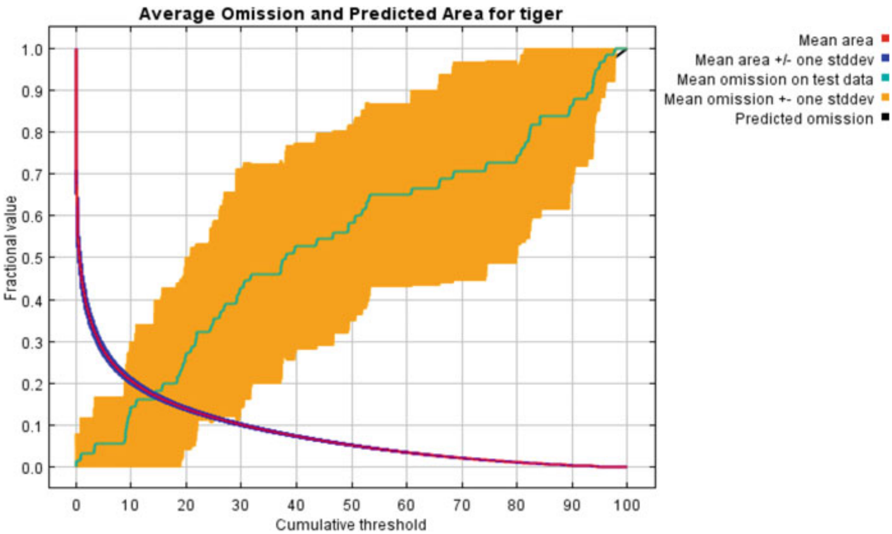


Fig. 19.15 Habitat suitability using Bioclim at 900 m grain size

ensemble model is shown in Fig. 19.16 for 30 m grain size with accuracy of 0.80 shown in Fig. 19.17. Here, 105 km^2 area is predicted to be suitable whereas the rest of the area of 230 km^2 to be unsuitable. Habitat suitability map developed by ensemble model at 900 m grain size was shown in Fig. 19.14 with an accuracy of 0.84 and 0.96 km^2 area predicted to be suitable and 239 km^2 area to be unsuitable from the total area of 335 km^2.

19.5.10 Importance of Bioclimatic Variables in Prediction of Panthera tigris *Habitat*

Figure 19.18 shows the jackknife test of AUC for Maxent without compressing the input parameter. Precipitation seasonality (BIO15) has the highest gain when used in isolation and holds the most useful information by itself, whereas annual precipitation (BIO12) has decreased the gain most when it is omitted. After BIO15, precipitation of coldest quarter (BIO19), precipitation of driest quarter (BIO17), and minimum temperature of coldest month (BIO6) prove to be important in predicting tiger's habitat. All other climatic variables are also significantly important. Table 19.9 shows the contribution of environment variables to the Maxent model which shows that temperature seasonality (BIO14) has the highest percentage contribution of 27.7% followed by BIO6 (21%) and BIO19 (9.1%). All other climatic variables don't contribute much to the model.

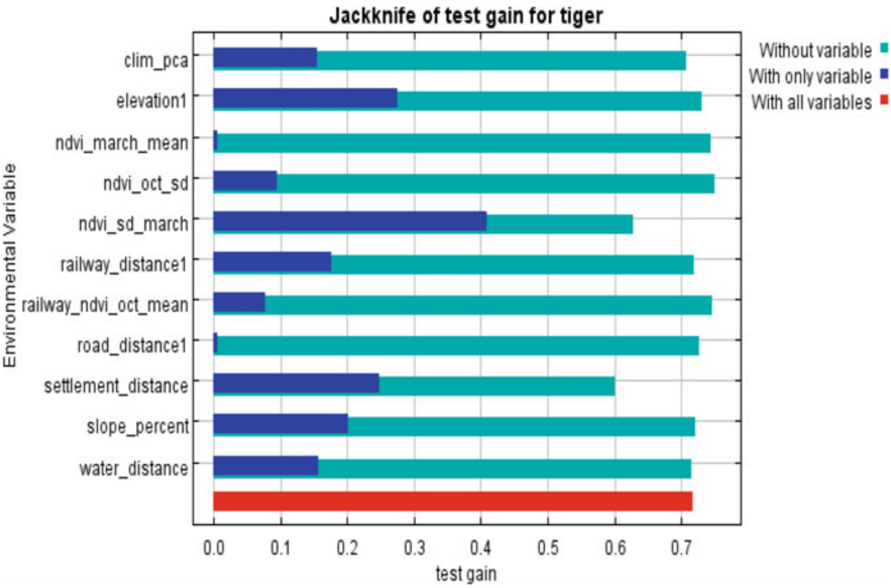


Fig. 19.16 Ensemble model at 30 m grain size

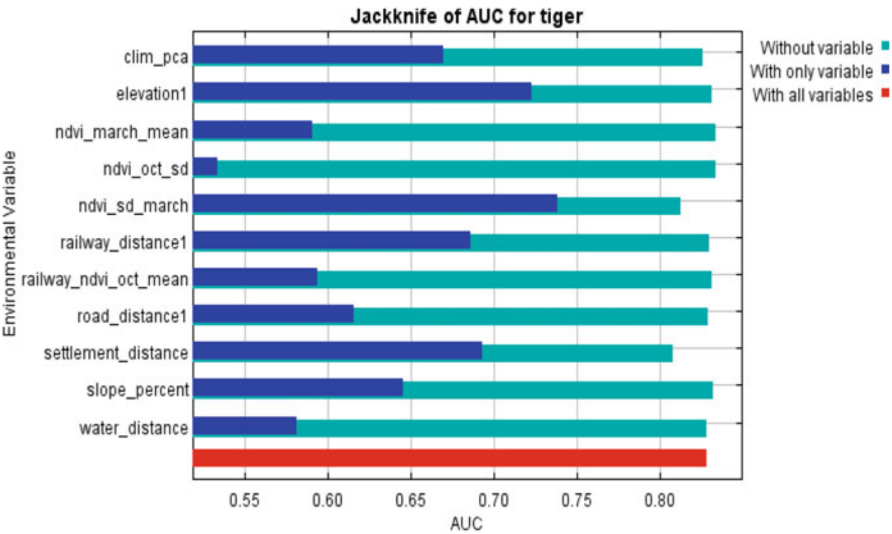


Fig. 19.17 Ensemble model at 900 m grain size

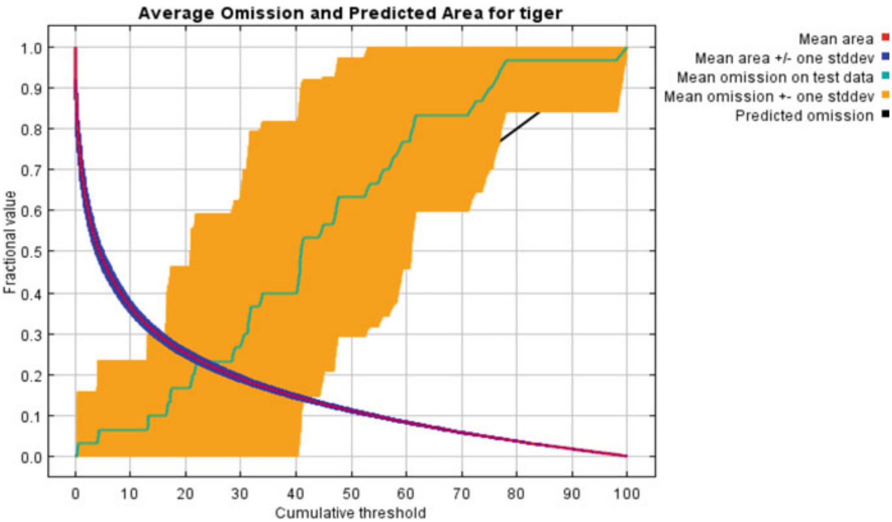


Fig. 19.18 Jackknife of AUC for Maxent without compression of input parameter

19.5.11 Comparison of Maxent With and Without Compression of Climatic Variables

Maxent model generated by including all the 29 input parameters shows the ROC value of 0.82 which is the same as after compressing the bioclimatic variables, i.e., 0.82. However, model's accuracy has been increased significantly when removing the bioclimatic variables, i.e., 0.86. Results show that climatic variables are not influencing the PT habitat and hampering the model's accuracy.

19.6 Discussion and Conclusion

The study was carried out to map habitat suitability of *Panthera tigris* in three ranges of RTR using three presence-only models. All models including Bioclim, ENFA, and Maxent performed almost equally well. While bioclimatic variables were not considered in the 30 m grain size analysis, the model's accuracy was better than 900 m grain size where bioclimatic variables were considered. This suggests that overreliance on the climatic variables and thus constraining model at coarse resolution are not required. Although this could be species specific, result is consistent with another study by Manzoor et al. (2018). Comparison among the SDM has been made with including all climatic variables, with compressed data, i.e., after performing PCA, and without including climatic data. There is no difference highlighted

Table 19.9 Percentage contribution of variables

Variable	Percent contribution	Permutation importance
bio14	27.7	8.5
bio6	21	2.3
Settlement distance	20.3	16.9
bio19	9.1	29.4
NDVI_sd_march	7.6	15.1
Water_distance	5.8	4.7
bio11	1.3	3.8
bio10	1.2	0.4
bio9	0.8	0.7
NDVI_oct_sd	0.8	5.3
bio5	0.6	0
bio4	0.6	0
NDVI_oct_mean	0.6	8.4
Elevation	0.4	0.3
Slope	0.4	1.7
Railway_distance	0.3	0.8
bio13	0.2	0.3
bio18	0.2	0
bio8	0.1	0
bio1	0.1	0
bio3	0.1	0
bio16	0.1	0
Road_distance	0.1	0.9
bio7	0.1	0
bio12	0	0
bio17	0	0.6
NDVI_march_mean	0	0.1
bio15	0	0
bio2	0	0

between both SDMs, i.e., before compressing and after compressing the input parameters, whereas accuracy has been increased significantly after removing the climatic variables.

Distance from settlement layer has contributed the most in both the Maxent SDM models at 30 and 900 m spatial resolution, whereas distance to waterbody has contributed the most in both the ENFA models of 30 and 900 m grain size, respectively. So, conclusion can be made that in RTR, presence of large number of settlements within the RTR and buffer zone disturbs the *Panthera tigris* habitat because of the fact that they are shy creature and tend to avoid the human presence. Source of water is an important factor for PT habitat as it is the basic requirement; they generally prefer the areas which has the availability of water so they can easily fulfill their thirst. All other environment variables also have considerable amount of contribution in predicting suitability. Slope, elevation, distance from railway tracks, mean NDVI, and SD NDVI show the significant contribution throughout both the SDM techniques. Railway tracks passing from the RTR near Rishikesh is always a hindrance to amphibian's habitat. Many Asian elephants (*Elephas maximus*) have died in accident in this zone, so one can relate this to PT habitat (Johnsingh 2006). Dense forest is mostly preferred by tigers, so higher value of NDVI proved this fact here. Flatter terrain has been preferred in comparison to rugged terrain.

The unavailability of prey's coordinates for RTR in GBIF is a major limitation for this study, as distribution of prey is a major factor in prediction of habitat suitability for *Panthera tigris*. This study opens up an immense future scope for another research; as such, comparison can be made between more advanced SDM algorithms such as random forest, CART, neuro-fuzzy, and ensemble which can be developed by including a greater number of SDM algorithms. A more detailed study can be done by including prey's suitability as an indicator in prediction of habitat's suitability at RTR.

Annexure

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Chapter 20
Assessment of Prospective Check Dam Sites in Kaimur Wildlife Sanctuary, Bihar, with Integrated Analytical Hierarchy Process and Geospatial Techniques

Shashi Sekhar, Nitu Singh, Mini Tiwari, Raj Kumar Sharma, Vikash Ahlawat, and Rajeev Kumar

Abstract A check dam is the most commonly used watershed management tool for the conservation of natural resources around the globe. However, the challenge lies in the identification of appropriate situate for the construction of the same within a stream network of watersheds. The task was carried out using a combination of the Analytical Hierarchy Process (AHP) techniques and Multi-Criteria Decision Analysis (MCDA). Heeding to an expert opinion, a number of geo-morphometric and topo-hydrological parameters like Topographic Position Index (TPI), Terrain Ruggedness Index (TRI), Topographic Wetness Index (TWI), Stream Power Index (SPI), Sediment Transport Index (STI), Stream Order (SO), and Slope Drainage Density (DD) were taken into consideration and accounted for depending on their rank to locate the sites best suited for construction of water storage structures like check dams. A total of 15 potential sites, answering to the suitability of the study under reference, were identified coupled with several measures that can be undertaken for the revival of the degraded forest lands. This study is envisaged as a positive step towards the conservation of Kaimur Forest as it will enhance the soil fertility besides making the forest and the sanctuary by extension a better place for the natural wild species to live in.

Keywords AHP-MCDA · Check dam · Kaimur · Geo-morphometric

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20.1 Introduction

Water is a key element for the existence of life on planet Earth, and the animal kingdom is hardly an exception to the rule. With depletion of water as a natural resource assuming alarming propositions, thanks to unwarranted anthropogenic interventions and resulting environmental imbalances, the need of the hour is to save water for the proverbial "rainy day," and this is where water harvesting techniques along with check dams and other water storage structures come into play. Water storage structures apart from being an important component of watershed development are known to be versatile as they not only collect and store water but also ensure the recharge of groundwater resources (Ahmad and Verma 2016; Rasooli and Kang 2015).

The primary objective of the study is identification of a potential site for construction of a check dam in the forest area in a bid to enhance its "carrying capacity," and since the structures are complex in design and are expensive to build, their numbers for the entire watershed area are limited (Yadav et al., 2021; Rahmati et al. 2020). Comparatively, the RS and GIS tools are known to provide analytical results in a fast and cost-effective manner (Singh et al. 2009). In a way, identification of apposite location for edifice of check embankment is the first concerted step in the direction of conservation and management of natural resources.

The research work entailed integration of the analytical hierarchy process (AHP) techniques and multi-criteria decision analysis (MCDA). AHP takes recourse to eight geo-morphometric and topo-hydrological parameters like topographic position index (TPI), terrain ruggedness index (TRI), topographic wetness index (TWI), stream power index (SPI), sediment transport index (STI), stream order (SO), and slope drainage density (DD) for detection of a suitable site (Jain et al., 2021; Rahmati et al. 2020). Slope along with other parameters lies at the heart of this task although in the Indian context, precipitation is an essential spatiotemporal variable owing to the topography and monsoon-bearing winds (Dorfeshan et al. 2014).

Kaimur is an important district for cultural and ecological reasons. The undulating topography of Kaimur forest is home to a number of scarce species like Indian gazelle, Indian *Panthera pardus* (leopard), four-horned antelope, and Indian antelope (blackbuck), besides more than 100 species of birds (Singh 2004; Choudhary 1966). The sanctuary also boasts of more than 70 archaeological sites rich in antiquarian remains like pottery, coins, inscriptions, and prehistoric rock paintings (Tiwary 2013). The ecology of the sanctuary has been adversely affected by a combination of anthropogenic activities and environmental factors like forest fragmentation, land degradation, overgrazing, and climate change (Abhijitha et al., 2021). Changes in the land use pattern and erosion control works initiated by the resident human population in the region usually prompt strong geomorphic responses in watershed regions which is evident in the morphological evolution of river channels and drainage patterns of the region (Boix-Fayos et al. 2007). Afforestation leaves narrow channels, developed pavements, stream incision, meanders, colonization of bars, and short sediment supply in its wake (Liébault and Piégay 2002; Stott and Mount 2004; Liébault et al. 2005).

Interestingly, this GIS-enabled technique was designed and developed for providing solutions to environmental issues through analytics at the outset. Later, advancements of geospatial techniques opened new vistas for identification of suitable sites for watershed management after accounting for soil characteristics, topography, geology, and drainage density and stream order (Atiq and Arslan 2019; Chenini et al. 2010; Rahmati et al. 2020). Nature-based solutions are central to management of resources, land, water, and living beings as they promote conservation and sustainable use of resources in an equitable manner (Bennett 2004).

Site suitability evaluation, a subset of watershed management, envisages water conservation along with an increase in natural vegetation cover, sediment reduction, and improved productivity for all land uses (Malczewski 2006; Malczewski et al. 2003). The natural forest cover intercepts runoff and helps recharge aquifers while protecting rivers and streams from soil erosion. The effect of forest as an environmental tool depends on factors like soil type, micronutrients, rainfall, and management practices along with other inputs, and efficient planning is possible with the use of latest technology subject to a proper understanding of prevalent ecological conditions. Site suitability analysis is interplay of various decisions related to selection of criteria, major land use paradigms, and arrangement of criterion based on the above said method followed by determination of suitability limits for each class of the parameters that are used in the study area.

It is paradoxical that state of Bihar, located in the Indo-Gangetic heartland, has not been able to leverage its perennial rivers for water collections or water-harvesting projects. Kaimur Wildlife Sanctuary, one of the remotest areas which is situated connecting two prominent states of Peninsular India, i.e., Bihar and Uttar Pradesh, has witnessed a vacant in the research work especially related to water issues and its management. Kaimur Range is blessed with many rivers and watercourses, i.e., Son in the south, Tamsa in the north, and few other like Karamnasa, Durgawati, Tilhar, Suvra, Kudra, and Varuna rivers in between off, and bifurcates the whole range by constructing many watershed or river catchment area. Previously, it was observed that authorities' view point on the subject was not serious and water-saving approach can be planned with technological tools to utilize the undulate topography of the Kaimur Range. The forest division has piloted many schemes to protect and conserve the sanctuary like afforestation drive, conservations of flora and fauna, preparations of catchments near water tables, etc., mostly within the confines of the forest area. Hence this research work under reference will come as a handy tool for successive optimal management practices in the region correlated with water management, and the exercising of novel techniques will definitely help the government authorities to protect the ecology of the sanctuary. The research work can serve as the baseline source for the preliminary screening and planning by the government authorities, forest conservators, and wildlife protectors. Besides availability of data, the continuance of the drought-prone uplands of the sanctuary, like the Adhaura region, might still be able to keep its date with dense forest patches after the construction of water storage structures. However, there is ample of evidences that the selection of potential suitable sites can successfully address the water scarcity of any region (Ajibade et al. 2020). Such kind of work can also be used as a tool to facilitate assessment of climate change and its impact on environmental and socio-economic aspects, which envisage the formulation of relevant adaptation policies (Qin et al. 2008). It is hoped that such study shall serve as a stepping stone for many other research initiatives to be undertaken in the near future for this region.

20.2 Study Area

In 1991, the present Bhabua subdivision (Kaimur) was formed out of Rohtas. In a geographical area, the district can be separated into two main parts, viz., (1) prairie area and (2) mountainous area. The mountainous area comprises of Kaimur plateau which covers almost 95% of Kaimur Wildlife Sanctuary. The sanctuary is located at the eastern extremity of Vindhya Hill ranges which is known for its unique tableland in a state like Bihar. The Kaimur district occupies a vicinity of 3363 sq.km out of which more than 1342.22 sq.km areas fall under the forest area of the Kaimur Wildlife Sanctuary including the forest region of the adjoining district of Rohtas. The sanctuary is located at 24°54′29.56"N-83°31′50.54″E in the Kaimur Range where several waterfalls like Karkatgarh Waterfall and Telhar Kund are major tourist attraction places. Most of the province of the district comes under the terrain of Indo-Gangetic belt. The western side prairie area is fringed by the two important rivers, the Durgawati River and the Karmanasa River. On the eastern side, the Kudra River flows and covers the Rohtas district (east flank). From the northern side, it is bordered with Buxar, the district of Bihar, and at the other side with Ghazipur district (UP State). From the western side, two adjoining districts of UP, Chandauli and Mirjapur, confine the range. And from the southern side, it touches the boundaries of Jharkhand State (Garhwa district). On the east is the district of Bihar State. The alluvial region is generously endowed with groundwater resources to a depth of 150 m below ground level (bgl) with its discharge varying between 100 and 200 m^3/h. (CGWB Annual Report 2010). The entire sanctuary area is endowed with natural Sal forest, the northern tropical mixed dry deciduous forests, Boswellia forests, and medicinal plants (Bhattacharyya and Ghosh 2004). Our study emphasizes on the aim to enhance forest resources through the implementation of latest technologies and techniques with the prime focus on the integration of management practices to increase forest efficiency in an optimistic manners which is explicitly elaborated in Fig. 20.1.

The State of Bihar is divided into two climatic zones, the Sub-Himalayan and the Gangetic Plains. And the district of Kaimur exhibits extreme climatic conditions with the mercury rising to 450C and plummeting to 40C in summer and winter, respectively. The monsoon-bearing winds usher in maximum precipitation in the months starting from July to September, while the retreating monsoon is responsible for some precipitation in the month of October in Kaimur. The distribution and departure of the rainfall from 2014 to 2018 have also shown the average precipitation of the selected study area as in Table 20.1.

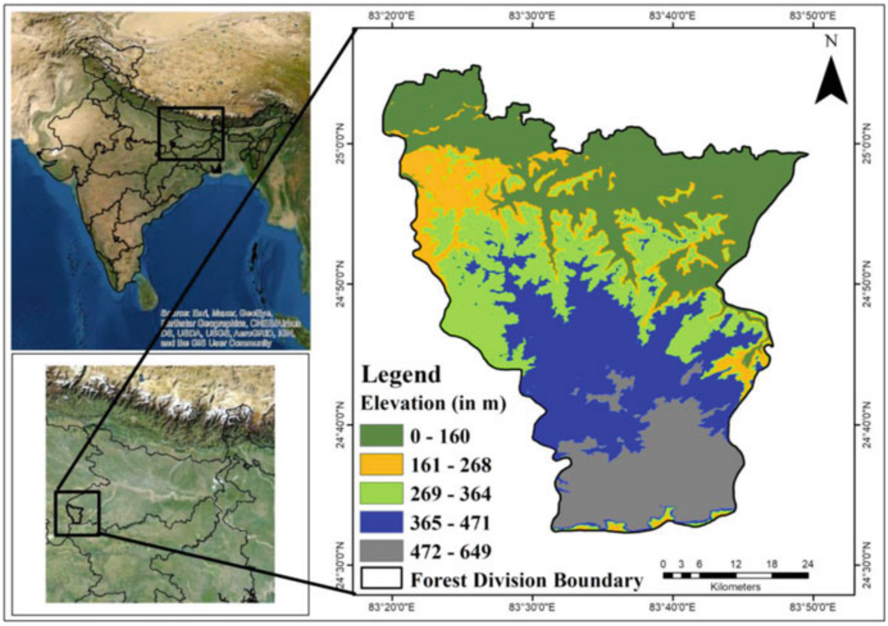

Fig. 20.1 Map of the study area

Table 20.1 Rainfall distribution of 5 years 2014–2018

Rainfall(mm) distribution and departure %										
	2014		2015		2016		2017		2018	
Year/ Months	RF	DEP %	RF	DEP %	RF	DEP %	RF	DEP %	RF	DEP %
January	14.2	−46	29.7	13	13.1	−51	0	100	0	−100
February	31	89	0	−100	0	−100	0	−100	0	−100
March	11	10	10.7	7	10.1	1	1.4	−86	0	−100
April	0	−100	28.6	420	0	−100	0	−100	0	−100
May	8	−57	8.9	−52	3.1	−84	0.4	−98	0	−100
June	19.5	−85	170.7	30	55.7	−58	53	−60	81.1	−38
July	213	−32	390.9	25	400.5	28	424.4	36	364.6	17
August	291.6	−3	196.9	−34	390.5	30	294.4	−2	216.3	−28
September	150	−41	77.5	−69	251.9	0	55.6	−78	187.5	−26
October	35.5	−16	3.7	−91	39.9	−6	0	−100	6.3	−85
November	0	−100	0	−100	0	−100	0	−100	0	−100
December	0	−100	0	−100	0	−100	0	−100	0.6	−91

The rainfall (RF) which is shown above in mm (millimeters) is the mathematical calculations of average distributed rainfall at different locations (metrological sites) of the district, whereas indication of zero is the non-availability of data (source: IMD)

The tillage practices in the aforesaid district account for four agricultural cycles, namely, Bhadai, Aghani, Rabi, and Garma. However, the highland is characterized by low agricultural intensity and productivity due to the acidic nature of its soil. But the district as a whole exhibits alluvial to sandy loam soil with medium to light texture, medium to high potash content, and low nitrogen.

20.3 Methodology and Preparation of Datasets

The terrain surface, drainage pattern, slope or elevation, watershed basin boundaries, and relevant geomorphic factors which are considered as important factors for suitable dam sites can be acquired from remote sensing images. To obtain hydrological attributes, various hydrological models (Fig. 20.2) are used as input functions in this study, and the premium one is Shuttle Radar Topography Mission-Digital Elevation Model (SRTM-DEM) satellite data. There are numerous research works based on satellite imagery especially on the use of DEM data, the only difference being the spatial resolution. The accuracy of drainage network analysis obtained from DEMs and natural network in the raster format is similar, but the appearance may seem different due to the spatial resolution (Hosseinzadeh 2011).

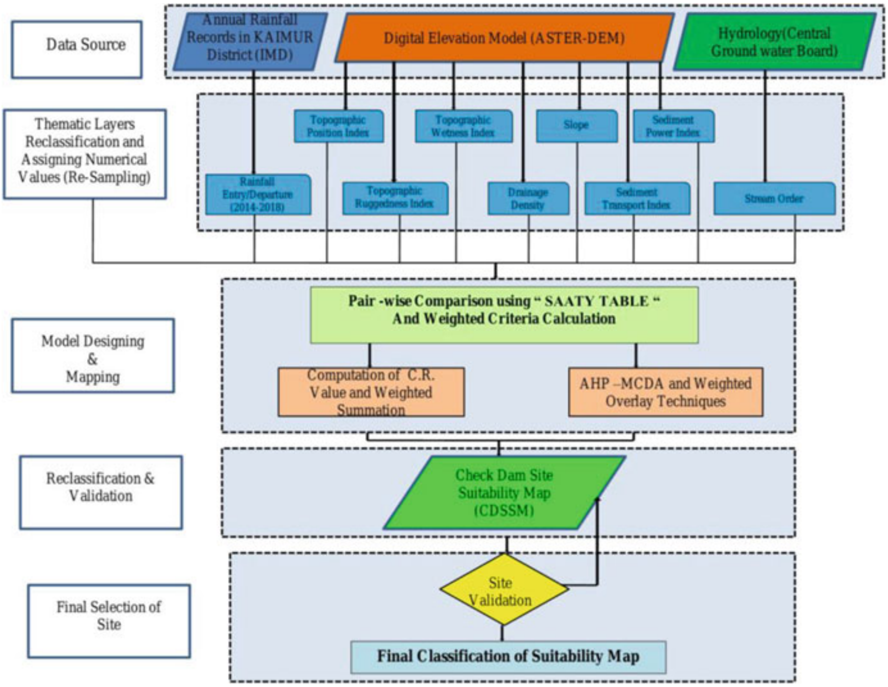

Fig. 20.2 Methodological framework of assessment of the prospective check dam sites

For the selection of appropriate spots as the main water storage structures, the guidelines and the basic criteria of Integrated Mission for Sustainable Development (IMSD) have been followed (IMSD 1995; Padmavathy et al. 1993; Bamne et al. 2014). Likewise:

- The inclined area or the slope should be below 15% of the total area.
- The selected terra firma should be either an agriculture river bed or uncustomized water body or a barren land/remote area, hinterland and forest, etc.
- The permeation rate of soil should be low.
- The form of soil would be in the category of sandy-clay loam.

20.3.1 Topographic Position Index (TPI)

As defined by different researchers (Weiss 2001; Tağıl and Jenness 2008), the TPI or topographic position index is a useful tool for classifying slope positions and landforms. TPI is a measurement of topographic positions classified into three classes corresponding to upper, mid, and lower slopes (Tağıl and Jenness 2008). Positive TPI values specify that the locations are on elevated as compared to the average altitude of the bordering creases, while the TPI values with negative captions specify that the elevation of the sites is at a lower level relative to the nearby basins (Biswas et al. 2014). According to Weiss (2001), almost zero values of TPI specify that it may be a flat area or the slopes of that area can be considered as a constant slope.

$$\mathrm{TPI} = Z_0 - \sum\nolimits_{1-n} Z_n / n \tag{20.1}$$

In the above formula, the nodal point elevation is Z_0, the grid elevation is Zn, and the overall number of neighboring points is indicated as n. According to Fig. 20.3(a), the range of TPI lies from −197.6 to 184.9.

20.3.2 Topographic Ruggedness Index (TRI)

Riley in 1999 developed a technique for the measurement of magnitude of elevation through differences among the adjoining cells with a digital elevation grid, and he articulated the term as terrain ruggedness index (TRI). In the whole process of measurement, the variations in the elevation values of a center cells and nearby eight cells are calculated. Afterwards the square of all the eight values of altitude difference creates positive standards and also makes the average of the square values (Riley et al. 1999). The derivation of the terrain ruggedness index is then calculated for the center cell by taking the square root of the calculated average. Such calculation is then conducted on every cell of the DEM using hydrological tools. In our study area, Fig. 20.3(b) clearly indicates that it ranges from 0.11 to 0.89.

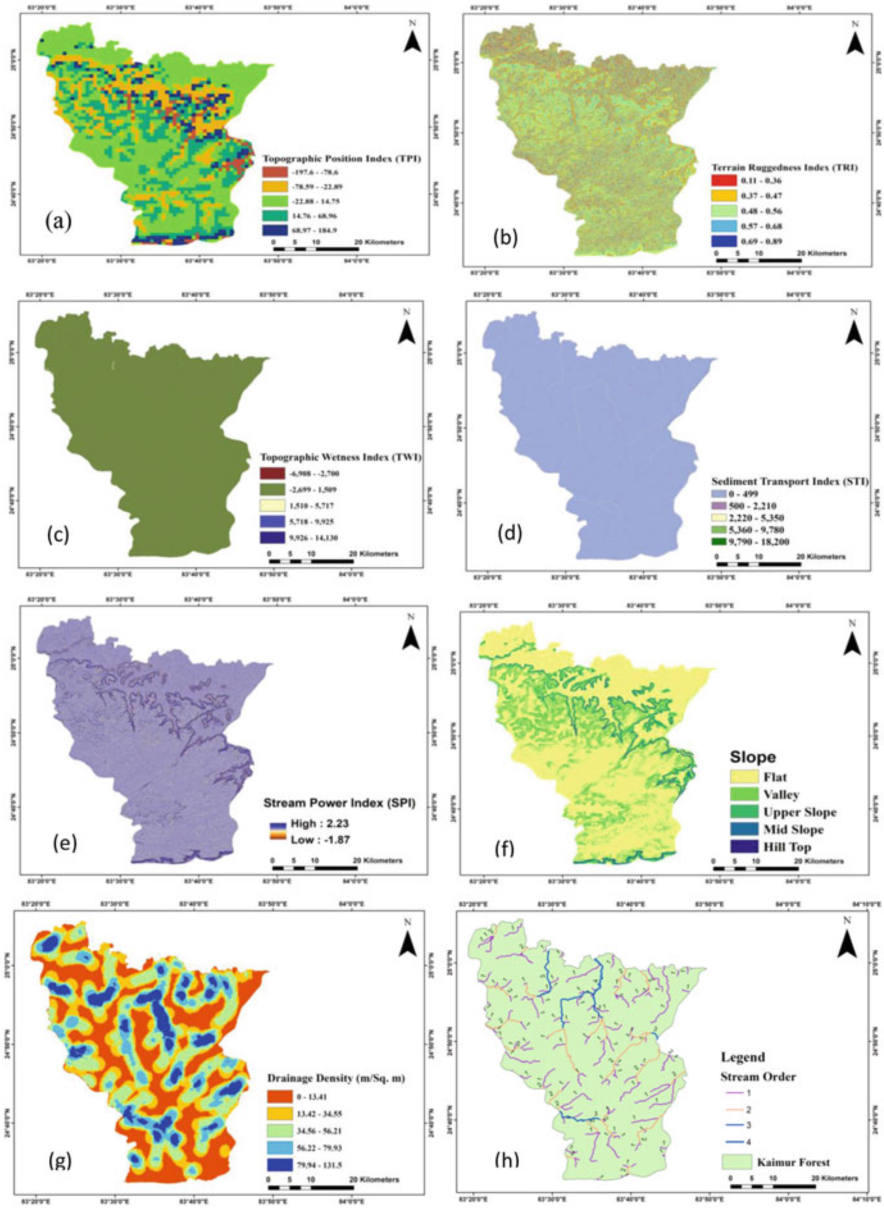

Fig. 20.3 Maps demonstrating the values of eight parameters used in present study (**a**) Topographic position index (TPI), (**b**) terrain ruggedness index (TRI), (**c**) topographic wetness index (TWI), (**d**) sediment transport index (STI), (**e**) stream power index (SPI), (**f**) slope, (**g**) drainage density (DD), and (**h**) stream order (SO)

$$\text{TRI} = \left[\sum (Z_c - Z_i)^2\right]^2 \tag{20.2}$$

where Z_c is the central cell's elevation as well as Z_i is the one of the eight neighboring cell's (like $i = 1, 2 \ldots 8$) elevation.

20.3.3 Topographic Wetness Index (TWI)

TWI is an indicator that measures the potential area where water can tend to accumulate. Beven and Kirkby (1979) projected the term TWI, within the runoff model, TOPMODEL, which is generally used in hydrological progression to analyze the topographic run. TWI is considered as an important function for the calculation of slope as well as for the upstream which contributes the flow of direction in quadratic width (area per unit) (Różycka et al. 2015). High index values indicate the high potential of water accumulation due to low slope. The index is a suitable variable for hill slope areas as compared to flat areas where the accumulation will be very large; hence, TWI cannot be considered as an appropriate variable.

$$\text{TWI} = \ln\ (A, \tan\beta) \tag{20.3}$$

Here "A" is considered as the confined upslope part challenging over a specific point/unit contour span, and local slope is defined by "$\tan\beta$." With Fig. 20.3(c), the study area falls under TWI ranges −2699 to 1509.

20.3.4 Sediment Transport Index (STI)

The STI tools (sediment transport index) illustrate the erosion and deposition process (Moore and Burch 1986). Besides end-to-end distance of slope which is an important feature in the Universal Soil Loss Equation (USLE), the STI tool can also be applied on 3D surfaces (Burrough et al. 2015). The log combines upslope area (As) and slope (β) under the assumption that the contributing area is directly related to discharge. As the Fig. 20.3(d) indicates, the maximum areas fall under the value ranges up to 499.

The index is calculated as:

$$\text{STI} = (A_s/22.3)^{0.6} * (\sin\beta/0.0896)^{1.3} \tag{20.4}$$

In GIS, STI is calculated as- Power("Flow Accumulation Area_Raster"/22.13, 0.6) *Power (Sin("Slope Raster"/0.0896),1.3).

20.3.5 Stream Power Index (SPI)

According to Moore et al. (1993) and Burrough et al. in 1998, the stream power index is a product of the catchment area and slope gradient. Basically, it is a measurement technique of the acrid control of transboundary stream. The potential flow erosion at the specified source else at a given point on the topographic surface can be describe under the stream power index (Pei et al. 2010). The STI and erosion risk increase with an increase in the catchment area and slope which implies that there is an increase in the quantity of water which is added by the upslope regions along with an increase in the velocity of water flow.

$$\mathrm{SPI} = A_s * tan\beta \tag{20.5}$$

where A_s denotes the upstream area and β is the slope. In this study area, Fig. 20.3(e) clearly indicates the SPI ranges from −1.87 to 2.23.

20.3.6 Slope

Slope is the most important variable for analyzing terrain in hydrology, site planning, conservation, and infrastructure development. It is a metric that is important to describe surface hydrological developments including soil erosion, overland flow, and sediment transportation (Denton et al. 2018). The slope of this study area was derived from SRTM-DEM satellite imagery using ArcGIS software. In our study area, Fig. 20.3(f) shows the slope ranges from 74 to 649 m. However, the proposed sites for water storage embankments construction lie within 100–120 m range.

20.3.7 Drainage Density (Line Density)

Drainage Density may be defined as the total length of the stream(s) or river(s) that lie in a basin divided by the total area of the basin. Moreover, it is an extent to measure how sufficiently or inefficiently a watershed is worn out by stream channels. DD stands one of the factors that define basin morphometry in addition to basin area, length, shape, and relief attributes. With Fig. 20.3(g), it is apparent that the Kaimur forest area mostly lies in the range between 0 and 13.41 m/sq.m.

The potential sites for the construction of check embankments lie in the range of 56.21–131.5 m/sq.m which is a considerably noble indication. These areas serve as suitable sites for regeneration of new forest patches.

20.3.8 Stream Order

It is one of the important aspects commonly used by geographers, geologists, and hydrologists to classify a stream. The stream order is a degree of the comparative extent of streams and drainage areas. On the basis of increasing size and strength, streams are classified in1–12 order. In this study, the "Strahler method" is used which states that all links without any tributaries are assigned an order of 1which is referred to as the first order and so on (Strahler 1957). The Fig. 20.3(h) that depicts stream ordering was obtained through SRTM-DEM data in the working environment of hydrological tools in the software ArcGIS version 10.3.1. The spatial analyst and hydrological tools are altogether applied for extracting the streams and then stream order tool used to derive the ordering of the streams.

In general, when two different orders of streams join upstream, then the higher ordering preference would be given to the downstream streams. In this study area, there is an availability of up to fourth order of streams.

20.4 AHP-MCDA Criteria

MCDA can be defined as a set of approximations, methods, models, techniques, and tools that start with the first step to construct the hierarchy of the parameters and use AHP as the methodological support (Moreno-Jiménez and Vargas 2018; Dai 2016). This approach in decision-making is considered as effective when criterions are well-known. However, in the wayward to approaching newer problems where no any standards are prescribed and also when previous criterions are convicted, the abstractive criteria will be used to evaluate the alternatives (Saaty 1987; Banai-Kashani 1989). An AHP method refers to pairwise comparisons of two kinds of parameters within a fixed reciprocal matrix set according to their rank (Gupta et al., 2021). These comparison matrices are based on importance of each parameters in the form of ranks to each criterion (Saaty 2003). For instance, 1 is given for the equal importance and 9 for extreme importance to the parameters (Table 20.2). Finally, priority weightage can be calculated using values of eigenvector and comparison matrix which is usually present in the form of pairs (Table 20.3). The extent and robustness of consistency ratio (CR) determine the overall judgment criteria to validate how stable the decision has been made with comparison to the random outcomes (Saaty 1987). Based on the available literature and reports, it has been proved that a CR value of 0.1 exhibits judgment at the limit of consistency,whereas CR values greater than 0.1 may be accepted or rejected depending on the nature of the events entirely (Saaty 2003; Saaty 2008). In this instance, the consistency ratio 0.048 falls on the safe ground. Moreover, a greater CR value like 0.9 reflects that the pairwise decisions are considered as random decision and completely unreliable. Hence, for more reliability and consistency of the analysis, the recommended CR value in AHP criteria should be less than 10% (Saaty 1987; Saaty 1990).

Table 20.2 Reference table (Saaty 1987, 1988)

The fundamental scale for pairwise comparisons		
Intensity of importance	Definition	Explanation
1	Equal importance	Two elements contribute equally to the objective
3	Moderate importance	Favored one element over another
5	Strong importance	Experience and judgment strongly favored one element over another
7	Very strong importance	One element is favored very strongly over another; its dominance is demonstrated in practice
9	Extreme importance	The evidence favoring one element over another is of the highest possible order of affirmation

Intensities of 2, 4, 6, and 8 can be used to express intermediate values. Intensities 1.1, 1.2, 1.3, etc. can be used for elements that are very close in importance
Source: Saaty 1987, 1988.

Table 20.3 AHP matrix computed table

	Slope (%)	SPI	STI	Line density/DD	TWI	TRI	TPI
Slope (%)	1	3	2	0.5	3	3	3
SPI	0.333	1	0.5	0.333	0.5	0.5	0.5
STI	0.5	2	1	0.333	0.5	0.5	0.5
Line density /DD	2	3	3	1	3	3	3
TWI	0.333	2	2	0.333	1	0.5	0.5
TRI	0.333	2	2	0.333	2	1	0.5
TPI	0.333	2	2	0.333	2	2	1
	Consistency ratio = 0.048						

The number of comparisons can be obtained using:

$$\text{no. of comparison} = (n-1)/2 \tag{20.6}$$

where n is the number of parameter.

The consistency index (CI) (Saaty 1987) can be obtained using:

$$CI = \frac{\lambda_{max} - n}{n-1} \tag{20.7}$$

where λmax is the highest value of pairwise comparison matrix and n is the number of classes.

Then consistency ratio (Saaty 1987) is obtained as:

$$\text{CR} = \text{CI}/\text{RI} \tag{20.8}$$

where RI is the average value or ratio index of CI for random value (Saaty 1987).

Table 20.4 Weightage summations

Slope %	23.285
SPI	23.285
STI	7.859
Line density (DD)	29.512
TWI	9.01
TRI	10.976
TPI	13.369

20.4.1 Weightage Aggregation and Site Selection

In this study, the criterion weights will automatically be calculated by the system after the pairwise rank is entered in the AHP model through the dedicated software. The weighted factor method offers a technique where each suitability factor is assigned a score, which is multiplied by the weight of that factor. The results of the product are then added, and a site composite score is obtained. The composite score is now being compared with a preset standard, which is further being used for the selection or rejection of a site (Banai-Kashani 1989). The suitable water storage structure point can be calculated on the basis of weightage summation of the above said parameters (Table 20.4). The module computes the consistency ratio (CR) associated with the pair comparison matrix based on the ranking given during the pre-analysis phase within the given model (Saaty 1987, 1988). The formula is given below:

$$\mathrm{S} = \sum_{i=0}^{n} W * X \tag{20.9}$$

where S indicates the suitability, W indicates the weight of factor, and X indicates the rank of factor.

20.5 Results

In this academic exercise, the results, by way of techniques and weightage summation of AHP-MCDA methodology, helped identify 15 potential sites, while the analytical effort with the planimetric map helped conclude that the blue, light green, and yellow shades represented highly suitable, moderate, and low suitable sites, respectively. These sites are central to the construction of check dams by dint of being part of suitable topographical and hydrological parameters. However, the study is not about focusing on the determination of any fixed distance between water storage structures because the primary aim is all about tapping maximum runoff in the sanctuary (Fig. 20.4).

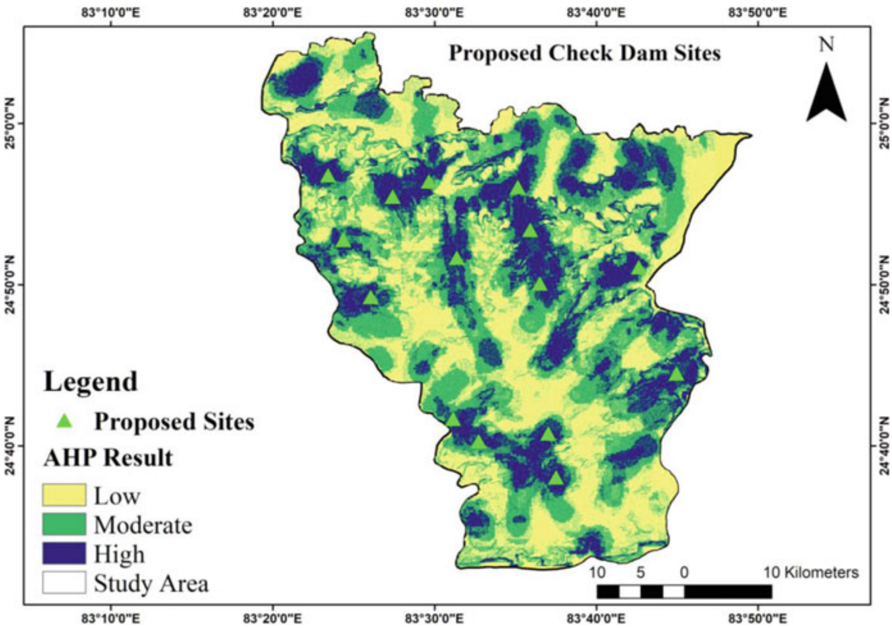

Fig. 20.4 Result showing proposed checks dam sites of the study area

20.5.1 Discussion

The theory of Brauman et al. (2007) states that nature-based solution offers concrete linkage between good health of ecosystem services along with human and other organisms. This relationship has tremendous potential in conservation and restoration of our ecological balance. The study embraces the pairwise comparisons and their calculations in a GIS platform in the backdrop of expert ranking (with respect to Saaty's table) for selecting potential sites for water storage construction or check dams. There is enough literature to support that such exercises meant to increase vegetative cover, reduce velocity of concentrated water flows,check unbridled flow of runoff, reduce soil erosion and check loss of sedimentation can be undertaken as a part of a major conservation mechanism to stabilize channels (Dutta et al., 2021; Liang et al. 2020). The deviation in the elevations, soil composition, and floral and faunal diversity along with water availability provides a great range of variation with respect to macro- and microecosystems of such type of sanctuary. In a world hurtling towards an environmental apocalypse, such measures are nothing short of a ray of hope for the conservationists and authorities waging a grim battle to save lives and livelihoods and safeguard the interests of indigenous communities along with the stability of the ecosystem, by designing a holistic conservation policy at district and state level.

20.5.2 Conclusion

It can be concluded that a spurt in the vegetative cover will soon find expression in soil retention capacity and availability of nutrients of the forest in due course of time, not to mention that restoration and maintenance of landscape connectivity will be indispensable in territorial planning with the objective of achieving sustainable development. The three main factors, viz., geological structure, hydrogeology, and climatology of the area, allocate the nature and existence of the groundwater. Since the estimations of proposed check dam site are fully lined, the groundwater hydrology is not supposed to differ much and shall not have any negative effect on the drainage or groundwater hydrology. Hence our study will play key role towards the afforestation drive as well as water reestablishment drive in the present scenarios. And the assessment of proposed water shed will not only help in recharging groundwater table but will also facilitate Bihar government's one of main mission "Jal Jeevan Hariyali." The results of this paper not only serve as the stepping stone for better management practices but also provide better insights to the authorities for the development of state's second tiger reserve in coming days. The geographical position of the sanctuary is well suited as it is nearby the other protected areas in Uttar Pradesh, Madhya Pradesh, and Jharkhand states. Although the current work is limited to the use of the combined MCDA-AHP technique for the identification of suitable sites for water storage structures, its potential in conservation and management of forests in particular and the environment as a whole cannot be undermined (Areendran et al., 2020). The Kaimur Forest Division is piloting an afforestation drive within the confines of the forest area, and the research work under reference will come in handy as a tool for subsequent optimal management practices in the region with the help of some of the latest technological advancements to save its ecology. The improvement in availability of water resources by way of establishment of new projects have always found favor with the natives of the Command Area. Further, the onus lies on the Department of Environment, Forest and Climate Change, Government of Bihar to assess the adverse impact of such projects, if any and to adopt appropriate measures to lessen the same. With the availability of water facilities, the villagers will not harness groundwaters through bore wells for irrigations. The positive impact on the migration from the villages will also be minimized as the farmers will able to earn a decent livelihood in their own villages and do not have to search for job in other places. Further, there could be an improvement in the standard of living as well as child education in the villages. The women in the nearby villages can also play a vital role with improving their status and work in their own farms or finding employment on others' farms to contribute to their family income after the construction of check dams as it will solve water scarcity problems in the Bhabhua districts as well as nearby districts like Rohtas. Besides the upgradation of socioeconomic conditions of the native people, the drought-prone uplands of the sanctuary like the Adhaura region might still be able to keep its date with dense forest territories following the construction of water storage structures. This study is the answer to the questions related to the degraded forest patches of the sanctuary, balance soil's moisture, and improvement of livelihood of the tribal community residing in or nearby the sanctuary. The sanctuary has a huge potential by way of development as an area for jungle safari , eco-tourism and forest based industries resulting in a win -win situation for all the stakeholders including the residents and the government along with Mother Nature. Kaimur range can be developed as an important heritage and archaeological site by leveraging various schemes of the government. The work will also serve as the updated chapter in the existing management plan of the sanctuary.

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